D5.1 Detailed Functionality Specification and Design of the Asset Management Tool Suite for TSOs, DSOs and RES Operators

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Big Energy Data Value Creation within SYNergetic enERGY-as-a-service Applications through trusted multi party data sharing over an AI big data analytics marketplace

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Author:	**ICCS**, ETRA, HEDNO, CUE, COBRA, URB, CIRCE, UBI, IPTO, KONCAR, UCY

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Peer reviewed by:

Partner	Reviewer
ELIN VERD	Marily Efstratiadi, Sotiris Tsakanikas
UBITECH	Konstantinos Perakis, Dimitris Miltiadou

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Abbreviations and Acronyms

Acronym	Description
AC	Alternative Current
AglA	Advanced Grid Level Analytics
AM	Asset Management
ANNs	Artificial Neural Networks
App	Application
AR	Augmented Reality
AS	Ancillary Services
BaU	Business as Usual
DC	Direct Current
DER	Distributed Energy Resources
DSO	Distribution System Operator
EC	European Commission
EPM	Enhanced Performance Monitor
EV	Electric Vehicle
FOIMO	Fault Occurrence Inspector and Maintenance Optimizer
FBNM	Flexibility Based Network Manager
FMEA	Failure Modes and Effects Analysis
FSP	Flexibility Service Provider
IoT	Internet of Things
LV	Low Voltage
MAIFI	Momentary Average Interruption Frequency Index
ML	Machine Learning
MV	Medium Voltage
NASE	Network Asset Sizing Engine
NPAE	Network Performance Assessment Engine
NPV	Net Present Value
OPF	Optimal Power Flow
OSO	Operational Scheduling Optimizer

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Acronym	Description
PV	Photovoltaics
PQ	Power Quality
RAE	Regulatory Authority for Energy
RIA	Reliability Index Assessment
RES	Renewable Energy Resources
SAIFI	System Average Interruption Frequency Index
SAIDI	System Average Interruption Duration Index
SCADA	Supervisory Control and Data Acquisition
SOH	State of Health
TSO	Transmission System Operator
VR	Virtual Reality
WP	Work Package

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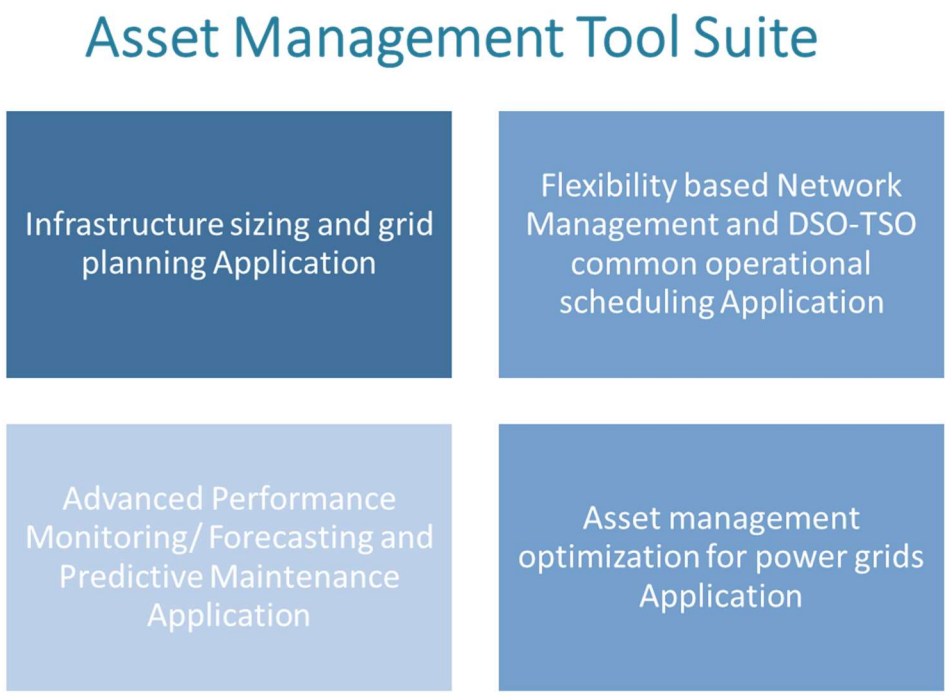
Executive summary

The current deliverable D5.1 “Detailed functionality specification and design of the Asset Management Tool Suite for TSOs, DSOs and RES Operators” reports the preliminary efforts and produced results of all WP5 tasks, T5.1, T5.2, T5.3 and T5.4. All four tasks aim to develop “Advanced Grid-level Analytics for Optimized Network and Asset Management Services and Applications”, targeting network operators as well as DER aggregators and RES operators. Each task aims to develop one application and thus all four of them consist the Asset Management Tool Suite, which comprises four applications in total, namely a) Infrastructure Sizing and Grid Planning Application, b) Flexibility based Network Management and DSO-TSO Common Operational Scheduling Application, c) Advanced Performance Monitoring/Forecasting and Predictive Maintenance Application, d) Asset Management Optimization for Power Grids Application , as seen in the following figure. The purpose of this deliverable is to deliver the design specifications of the energy applications, including a detailed description of the components and the functionalities consisting each application, the required inputs for each application, expected outcomes and description of the interactions of the application with the SYNERGY Big Data Platform (developed in WP3-WP4). Finally, for each application, the user stories that describe the experience of the end user while navigating through the application and the expected interface of each application are illustrated through a set of mock ups.



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A short overview of the purpose of each task and its associated application is given below:

- T5.1, named "Infrastructure sizing and grid planning in anticipation of RES, EV and storage technologies penetration" aims to deliver the **"Infrastructure Sizing and Grid Planning"** application. The application aspires to analyse in detail the state of the network for probabilistic expected demand and generation scenarios, calculate the network requirements in terms of flexibility, reinforcement and DER integration. The application simulates the operation of the network and utilizes all the necessary functionalities to assess the state of the network in terms of reliability, performance, and power quality metrics. Moreover, it provides solutions in terms of optimal planning and sizing of the network assets, e.g. optimal capacity for new substations and lines if needed, optimal sizing of new demand connections or DERs, etc.

- T5.2, named "Innovative Flexibility-based Network Management and Common Operational Scheduling of power grids" aims to deliver the **"Flexibility based Network Management and DSO-TSO common operational scheduling"** application. The application's objective is to coordinate scheduling of flexibility for intraday and day ahead markets between DSO and TSO according to a pre agreed coordination scheme. It facilitates network operators to perform their short-term planning schedule by leveraging the available flexibility from aggregators. For the TSO/DSO coordination a common interface for the DSO and the TSO to facilitate common operational scheduling is developed, which takes into consideration the flexibility requirements for both actors for congestion management needs, balancing needs and other relevant ancillary services.

- T5.3, entitled "Advanced Performance Monitoring/ Forecasting and Predictive Maintenance for Large-scale RES plants", will develop the "**Performance Monitoring and Predictive Maintenance**" application, which is responsible for the optimal operation, predictive maintenance and proactive avoidance of equipment faults of RES plants. This application is based on the forecasting and predictive analytics baseline algorithms and appropriate machine learning techniques in order to perform proactive diagnosis and categorization of equipment faults, monitor key power quality indicators, assess the potential of fault occurrence and deliver more accurate active/reactive power forecasts by leveraging PV plant assets' status and health.

- T5.4, entitled "Asset management optimization for power grids", will offer the **"Asset Management Optimization"** application. The application supplies the DSOs' and TSOs' maintenance operators with a variety of tools that facilitate maintenance management.

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Maintenance operators will be equipped with a number of analytics and forecasts that integrate the available data and provide new perspectives about the asset management. For example, this application includes modules that model the overall health score of each asset instance under maintenance component and provide forecasted scenarios about failures of assets. Moreover, the application will include augmented reality-based visualization as an additional user interface and an assistance to maintenance workers.

Each application comprises a set of components with certain functionalities which facilitate its various objectives. Furthermore, the work presented in D5.1 resumes on the work done in WP2 of SYNERGY, regarding use cases and requirements analysis[1], and the SYNERGY framework architecture[2].

The following table summarizes the proposed components to be developed within the application. Three out of the four applications contain two components each, while the application related to T5.3 contains three components. This table contains an updated version of information initially presented in D2.6.

App Category	Component	Use Case
Infrastructure Sizing and Grid Planning Application	Network Performance Assessment Engine	UC_5_1
	Network Assets Sizing Engine	UC_5_2
	Flexibility Based Network Manager	UC_5_3

[1] D2.1: *End-user and Business requirements analysis for big data-driven innovative energy services and ecosystems v1*

[2] D2.6: *SYNERGY Framework Architecture including functional, technical and communication specifications*

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App Category	Component	Use Case
Flexibility based Network Management and DSO-TSO common operational scheduling Application	DSO-TSO Common Operational Scheduler	UC_5_4
Performance Monitoring and Predictive Maintenance Application	Enhanced Performance Monitor	UC_5_5, UC_5_6
	Fault occurrence inspector and maintenance optimizer	UC_5_5, UC_5_6
	Operational scheduling optimizer	UC_5_9, UC_5_10
Asset Management Optimization Application	Network Asset Health Estimator	UC_5_7
	Network Predictive Maintenance Manager	UC_5_8

The current deliverable presents the detailed functionality specification and design of the Asset Management Tool Suite for network and RES operators and entails all the prerequisite analysis before the development and the implementation of the prototype energy applications of WP5. In this context, the deliverable includes two main pillars:

- Overview of existing solutions and BaU related to the tool suite, contextual information about the addressed actors and use cases by each one of the applications.
- Overview of the tool suite applications, components and their features, data and asset requirements, user experience and recommended technology stack

The prototype WP5 energy applications will be released in M22 within D5.2 which will contain the 1st version of the Asset Management Tool Suite for network and RES operators. At that stage, the

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applications will be also integrated into the SYNERGY platform, performing also data exchange and other interactions with the platform or other applications.

Tasks 5.1, 5.2, 5.3 and 5.4 will remain active until the end of the project (M42) and the WP5 Tool Suite will be progressively updated and validated during the demonstration phase. The final version of the Asset Management Tool Suite will be released in M42 with D5.3 documenting the final release of the energy applications, taking into consideration the feedback, findings and any new requirements that emerge from the demonstration phase in WP8.

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1 Introduction

1.1 Purpose of the document

This current deliverable D5.1 of the SYNERGY project named "Detailed functionality specification and design of the Asset Management (AM) Tool Suite for TSOs, DSOs and RES Operators", released as the 1st deliverable of WP5, aims to provide the feature specification and component design about the AM tool suite, which contains the energy applications relevant to asset management to be developed in the SYNERGY project, leveraging also the functionalities of the SYNERGY Big Data Platform & AI Marketplace (developed in WP3-WP4).

The specifications provided are based on the work that has been performed by the SYNERGY project up to the moment of writing. This also incorporates all the work presented in D2.1 regarding use cases and requirements and D2.6 regarding the SYNERGY framework architecture. The AM tool suite includes a set of applications that process grid data in order to perform critical power system functionalities, like optimal network planning, reliability/performance/power quality assessment and DSO/TSO coordination, to name a few. These applications will be provided as services to the different network operators, e.g. Power Transmission and Distribution operators. The services proposed in each application are in a web-based form (the end-user utilizes a web interface to navigate through the various features and functionalities), and a complementary AR-based mobile application. Their initial design is illustrated in the mockup schemes in the corresponding section of this document.

This document acts as an initial effort towards the implementation of the functionalities that compose the AM tool suite. However, it is possible that several enhancements might occur during the development phase of the platform and the feedback from the involved partners. Therefore, it is expected that the specifications and designs presented in this document will not represent the final version of the platform but a pivotal one. Each potential modification will be thoroughly described and reported in future deliverables D5.2 or D5.3.

1.2 Scope of the document

This document provides an in-depth assessment of the four applications which consist the AM tool suite and will be delivered as energy services. The assessment includes the description and the specifications of the tools and their components that will be developed within SYNERGY with the aim

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to address the interests and the needs of TSOs, DSOs and RES Operators. Example requirements are network planning decisions, DER sizing, optimal flexibility scheduling to tackle congestion and energy unbalances, asset management optimization and performance monitoring.

For each component within a specific application, the features that accompany the components are defined and described, the necessary data inputs are listed in table format and the expected outcomes from each application have been provided. In addition, relevant infographics show the interaction between the different applications and the SYNERGY platform, the data exchanges and communication aspects to be taken into account during the development phase. Finally, the user stories for each application are also described, through a series of mock up graphs which provide the user experience while navigating through the apps.

Last but not least, the document starts with an overview of existing solutions and BaU both in the market from the associated demo partners, but also in general in other research or industrial cases.

1.3 Structure of the document

This document is structured as follows:

In section 2, a brief overview of the energy applications of the platform is presented. Then, a series of completed and ongoing EC funded projects are described to identify the state-of-the-art strategies that are deployed in the existing similar applications, also with respect to the Competition analysis carried out in D10.5 Market Radar. Finally, the different use cases and the actors that participate in them are presented along with the architecture and interface of the SYNERGY platform.

In section 3, a detailed analysis of the AM tool suite is delivered. Each energy application or service is thoroughly described as a component of the whole platform, along with its features and specifications. The inputs and outputs of each module are presented in order to identify the interactions between them. Since these services are provided in a web-based platform, mock up schemes are depicted to give an idea about the user interface of the platform.

Finally, in section 4, general conclusions are drawn, following the previous analysis and description and future steps regarding the task's implementation are defined.

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2 Background

2.1 Short Overview of WP applications

SYNERGY project is delivering a tool suite for network operators, called "*Asset Management Tool Suite*" composed by 4 applications, as seen in Figure 1:

- Infrastructure Sizing and Grid Planning Application
- Flexibility based Network Management and DSO-TSO common operational scheduling Application
- Performance Monitoring and Predictive Maintenance Application
- Asset Management Optimization Application

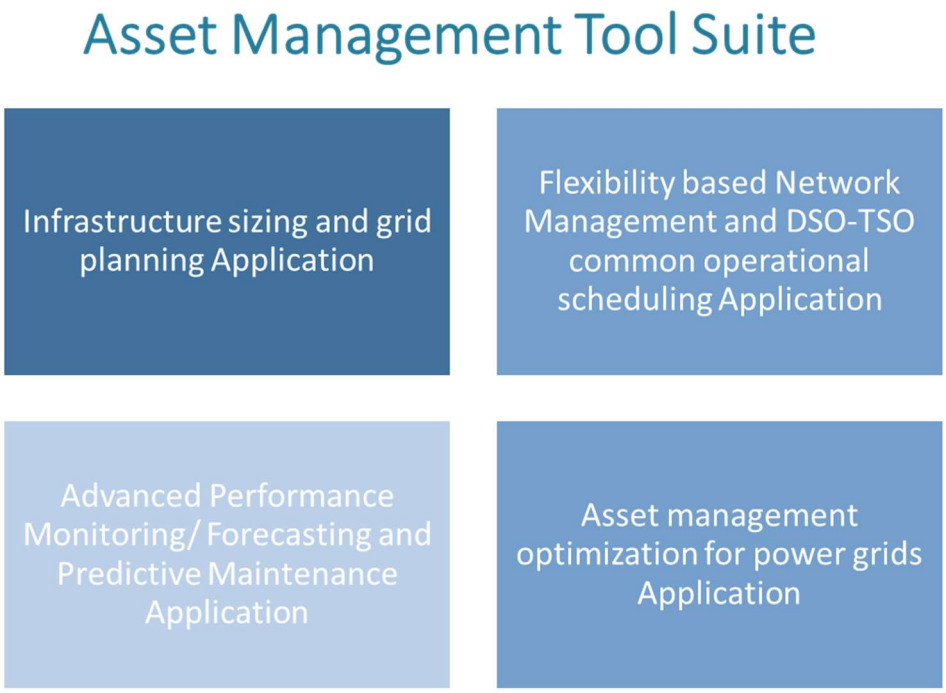

Figure 1: Asset Management Tool Suite

A short overview of these applications is presented in the following paragraphs:

The *Infrastructure Sizing and Grid Planning Application* simulates the operation of the network and utilizes all the necessary functionalities to assess the state of the network in terms of reliability,

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performance, and power quality metrics. Moreover, it provides solutions in terms of optimal planning and sizing of the network assets, e.g. optimal capacity for new substations and lines if needed, optimal sizing of new demand connections or DERs, etc.

The *Flexibility based Network Management and DSO-TSO common operational scheduling Application* facilitates network operators to perform their short-term planning schedule by leveraging the available flexibility from providers and network operators. For the TSO/DSO coordination a common interface for the DSO and the TSO to facilitate common operational scheduling is going to be developed and utilized, taking into consideration the flexibility requirements for both actors for congestion management needs, balancing needs and other relevant ancillary services.

Performance Monitoring and Predictive Maintenance Application is responsible for the optimal operation, predictive maintenance and proactive avoidance of equipment faults of RES plants. This application is based on the forecasting and predictive analytics baseline algorithms and appropriate machine learning techniques in order to perform proactive diagnosis and categorization of equipment faults, monitor key power quality indicators, assess the potential of fault occurrence and deliver more accurate active/reactive power forecasts by leveraging PV plant assets' status and health.

The *Asset Management Optimization Application* supplies the DSOs' and TSOs' maintenance operators with a variety of components that facilitate maintenance management. Maintenance operators will be equipped with a number of analytics and forecasts that integrate the available data and provide new perspectives about the asset management. For example, this application includes components that model the overall health score of each asset instance under maintenance component and provide forecasted scenarios about failures of assets.

Each application comprises a set of components with certain functionalities which facilitate its various objectives. Figure 2 summarizes the proposed components to be developed within the application. Three out of the four applications contain two components each, while the application related to T5.3 contains three components.

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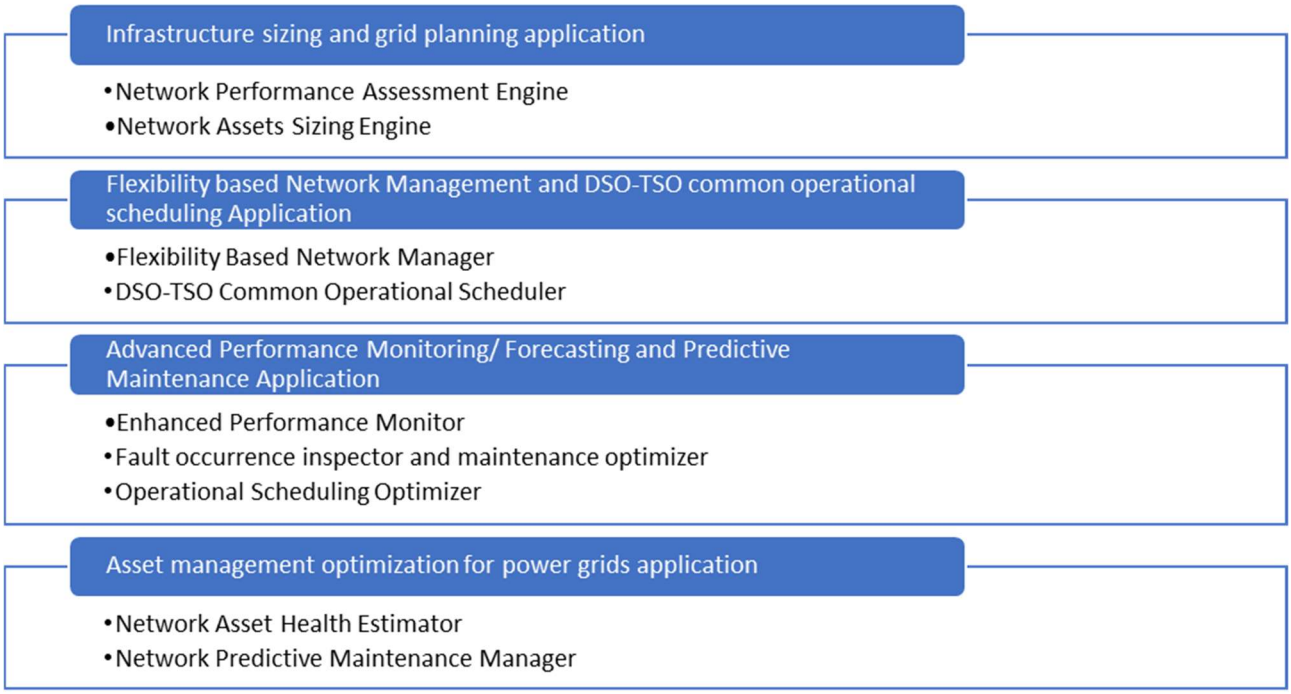

Figure 2: Asset Management Tool Suite and the related components

2.2 Overview of existing solutions

This section reviews the BaU for the SYNERGY demo partners and the functionalities of solutions available in the market regarding activities and strategies related to the energy applications and their components, that will be developed in WP5. The review is also in line to the activities carried out in WP10 and reported in D10.5 SYNERGY Market Radar v1. Apart from that, an overview of research and industrial projects that utilize the state-of-the-art technologies or relevant academic literature is also listed. Finally, potential enhancement that the proposed applications will bring through SYNERGY are also discussed.

2.2.1 Infrastructure sizing and grid planning

Several solutions are available in the market which target Network Management Platforms, related to utility's planning and operations. Those solutions, also described in D10.5, show the following features:

- Features assisting network evaluation activities are based on load flow, processing specific relevant information such as structure topology and condition parameters of network equipment.

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- Various loading and control tests are performed, by allowing network operators to optimally assess network conditions and optimally plan their networks.
- Processing of historical data and forecasts, such as historical outages, historical demand and , DER forecasts, in order to calculate relevant KPIs such as SAIDI, SAIFI and network planning indicators.

2.2.1.1 Current approaches and opportunities

Network Performance Assessment

Currently, a way to assess network performance is the reliability of a distribution system. Reliability can be interpreted as the probability of the system or equipment to be able to run its performance correctly, within a specified period, as well as with certain working conditions. In the following paragraphs, significant work about reliability assessment that have been proposed in the relevant literature are considered. Also, the current solution of HEDNO is presented along with a series of tools that utilizes this approach.

Literature Review - Network Performance Assessment

A method being used to calculate reliability is the Reliability Index Assessment (RIA). The RIA method is an approach used to predict interruption in components or distribution networks based on system topology and data regarding component reliability. RIA records failures that occur comprehensively on the equipment, then identifies the faults and analyses the failure modes. RIA also calculates the indexes that measures of the level of reliability in a distribution system, which are the System Average Interruption Frequency Index (SAIFI), the System Average Interruption Duration Index (SAIDI), the Momentary Average Interruption Frequency Index (MAIFI) [1].

Another significant method for determining the reliability of network elements is observing failures and outages in the distribution network of electrical energy. One way to analyze network failures' is gathering the data of joint-stock companies in an overall database, which will be continuously updated. In this way, the statistically significant set of data that will be created will be able to better and more quickly describe the real conditions of network equipment [2]. Reliability forecasting of a power system, such as an electrical distribution system, is a statement about the system's reliability performance that will be realized in the future based on current information. One proposal for predicting failures of the electrical distribution system is a three-layer Artificial Neural Network (ANN) model considering the system's failures. The ANN is trained using historical reliability data of an electrical distribution system [3].

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Network Performance Assessment - HEDNO's Approach

In the Greek distribution network, most network related issues (overvoltage, overheating of lines, congestion) are resolved during the design phase. For this reason, HEDNO conducts regular inspections and follows specific maintenance processes.

HEDNO operates failure databases which are based on MS – Access. The outage monitoring system (OMS) is based on decentralized MS- Access databases where all data related to failures are stored, including information about restoration time and the event handling. The OMS system serves as a failure monitoring system at all company levels and also supports power quality indices calculation (e.g. SAIDI, SAIFI).

Tools and Platforms for Network Performance Assessment

Different tools have been utilized for reliability assessment through demonstration projects. HEDNO participated in WiseGRID H2020 project and implemented the WiseGRID Cockpit for the purposes of the Greek demonstration. A list of existing tools and platforms are presented in the following table.

Table 1: Existing tools and platforms for network performance assessment

Tool Name	Short Description
SYNAPS phase 2	SYNAPS phase 1 can reliably predict faults on our networks. Phase 2 will develop next generation sensors ready for connection to our low voltage network, providing a fault location within 5 meters before they have occurred and preventing power cuts. More information can be found in this link.
CircuitSee	CircuitSee is a project that implements an approach to provide continuous fault-level monitoring based on machine-learning technology. More information can be found in this link.
MILES	MILES Better Fault Location is trialing a new way of finding faults on the network. The system helps field staff pinpoint the location of a fault down to a few meters so they can be fixed faster. More information can be found in this link.
Ubleam-ENEDIS	ENEDIS digitizes maintenance monitoring of its circuit breakers with Ubleam. In order to avoid the risks associated with human errors in the monitoring of its maintenance, ENEDIS has initiated a prevention approach using Ubleam technology. A new maintenance tracking tool was needed to meet 3 objectives:

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	An acceleration of processes A reduction in human errors A reduction of safety risks More information can be found in this link.
WiseGRID Cockpit	The WiseGRID Cockpit is a tool that offers several power grid functionalities like monitoring, observation, maintenance, etc., which are all displayed to the grid operator in an intuitive web-based User Interface. More specifically: Monitoring: modules processing data include temporal aggregation, grid status overview generation and congestion forecasting. Increased observability: includes the three-phase power flow module and the state estimation module which allow DSO operators to get an estimation of electrical parameters at all buses and lines of the grid. Maintenance module: it is the module in charge of registering the incidents that happen on the grid and manage the group of personnel in charge of solving those. Self-healing module: it is the module in charge of calculating the appropriate actions to be undertaken in the grid (either automatically or manually) in order to optimally solve the detected faults fast. This tool has been deployed in Mesogia, Kythnos, Terni and Crevillent pilot sites, which belong to HEDNO. More information can be found in this link.

Overview of Assets' Sizing

The main task of network planning and assets' sizing is to make studies for establishing new substations or extensions for existing substations in order to fulfill the demands of consumers. In order to manage and optimize the planning of the network multiple constraints and components must be taken into consideration, such as cost, overloads etc. Therefore, we have to confront a multi-criteria optimization problem. In the following paragraphs, significant works about network planning that have been proposed in literature are considered. Also, the current solutions of HEDNO and CUERVA are presented.

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Literature Review – Assets' Sizing

One proposal is introduced in [4], where a genetic algorithm (GA) with multi-criteria optimization technique is applied for solving the problem of system reconfiguration in a distribution system. Another research that proposes a multi-objective optimization is [5], in which two objective functions are introduced. The first objective function aims at minimizing the net present value (NPV) of the total investment and operation costs related to the network. The second objective function aims at maximizing a reliability index. The introduced problem is solved by using multi-objective particle swarm optimization (MOPSO) algorithm empowered with an innovative three-layer procedure that is provided to better manage the space of the decision variables.

Mixed Integer Linear Programming has also been used to solve problems regarding network planning. In [6] an optimal planning method for both the primary and the secondary grid is proposed. Integer programming problem is a mathematical or feasibility program in which some or all of the variables are restricted to be integers. The integer linear programming refers to the cases in which the objective function and the constraints (other than the integer constraints) are linear.

It is important to mention that distributed energy resources (DERs) play a crucial role in distribution networks due to their potential techno-economic benefits. Different optimization methods have been reported in the literature to solve DER planning problem. One of them is introduced in [7]. Considering the uncertainties of loads and of power production of wind distributed energy resources (DERs) and incorporating AC power flow equations make the DER problem increasingly challenging. Since AC power flow equations rather than DC ones are considered, the proposed model is a nonlinear and non-convex min-max-min optimization problem, and a tri-level decomposition algorithm is introduced to solve the problem.

Assets' Sizing – HEDNO's approach

In HEDNO, network expansion projects such as new substations, substations upgrade, new cables etc., are evaluated by investigating a number of network expansion planning strategies each of which is divided into expansion steps. Each expansion step represents a modification in the configuration of the network (which may be for example a new installation) and is associated with its relevant investment and operational cost.

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Table 2: HEDNO's BaU regarding assets sizing

	Description
Required Parameters	The annual load factor (f) of the network under investigation which is defined as the ratio of average load over a year to the peak load of the year A coincidence factor (m) which is the ratio of demand of the feeder at the time of System's peak to the peak demand of the feeder. Statistical Properties of Failures which may be derived from historical data. Costs of Losses (both energy and power cost). This include both copper losses and iron losses of transformers Investment Cost Annual Maintenance Cost of new installations. Negative Maintenance Cost may be inserted when components of the network are uninstalled. Additional Costs (i.e. licensing costs etc) Expected Life Span of new installations Scrap Value of installations (value after expected life span) Reliability Costs (i.e. ENS cost, Energy Interruption Cost), calculated according to the specifications of Reliability Cost Requirements Section and Load modelling features Interest Rate (%) Calculation Period Load Growth Scenarios.
Network Constraints	Voltage Maximum and Minimum Constraints Maximum Loading Constraints of equipment (line, cables, HV/MV transformers)
Expansion strategy Indexes	Net Present Value (NPV) Internal Rate of Return (IRR) Estimated payback period Estimated discounted payback period Cost- Benefit

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	Average Annual Rate of Return Return over Investment The expansion strategy selected is decided on the basis of the indexes above (most commonly the NPV is used as a criterion to select the best expansion strategy)

For the operational planning, also macroeconomic aspects are taken into account considering growth and demand. In addition, these aspects are also correlated with the DSO investment planning and country energy planning.

Assets' Sizing – CUERVA's approach

The following table intuitively summarizes CUERVA's approach on network assets' sizing.

Table 3: CUERVA's BaU regarding assets sizing

	Description
Development Prerequisites	a complete model of a Grid at Medium Voltage (MV). This can be developed in DIGSILENT software, a demand and generation algorithm forecast for each new client or generation source, historical (1 year at least) load and generation profiles (1 hour granularity) for the supply and generation points in the grid
Initial Scenarios	Once prerequisites have been fulfilled, the following steps have to be operated: E01: (Initial scenario): Full topology available; static data from the infrastructure complete. E02: Dynamic data from time series is included (ideally with an hourly granularity for a year); this time series must include demand on supply points and all the generation sources in the grid (PVs, Wind, Hydro, etc)
Iterative Scenarios	Both E01 and E02 will be the initial scenario for the network asset sizing manager. Then, the following scenarios are working as iterative steps of the network assets sizing manager:

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	E1: the full MV Model is included in *Power Factory DIgSILENT* with all the loads that the grid has and also the ones forecasted. The voltages from the boundary point should also be included. E2: Once the grid is modelled, different scenarios are simulated considering the new clients. These simulations will determine if a new client may cause an adverse effect in the grid conditions. For example, this simulation will indicate which cable section has to be replaced or the minimum section to admit these new clients. E3: New simulations are executed with possible assets re-sizing, taking into account adverse grid effects from the previous step. A cost analysis is performed to compare assets re-sizing with the current grid performance. E4: a final simulation is made with the worst conditions in this year for the user's grid (worst scenario for a load is when there is more consumption and less generation, usually around 20-21 pm of labor days & worst scenario for a generation is when there is more generation and less consumption, usually on weekends around 12-13 pm). This will be the critical condition for the network assets sizing

2.2.1.2 Enhancements offered by SYNERGY

The infrastructure sizing and grid planning activities in the BaU for both distribution and transmission grids will be enhanced through the developments proposed in the project by:

- Facilitating the evaluation of network performance and reliability assessment by including uncertainty of generation and demand through the analysis of probabilistic scenarios
- Exploiting the generated forecasted data and historical data available in the SYNERGY platform to create test scenarios and improve network planning
- Supporting the transition from a conservative planning for a long future period to a more flexible predictive planning, that reports network performance, grid status awareness of the near future (next weeks and next months) and uses flexible capacity instead of traditional expansion investments
- Feeding into DSOs and TSOs high-value information to manage their assets and networks

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2.2.2 Flexibility based network management and DSO-TSO common operational scheduling

There are a few solutions available in the market which target Network Management Platforms, related to DSO-TSO coordination and flexibility based network management. Those solutions, also described in D10.5, show the following features:

- There is a trend towards collaboration of system operators and a need to regulate this coordination.
- Functions that aim to facilitate optimal scheduling for the operators to manage congestions and unbalances utilize features such as generation and demand short term forecasts

2.2.2.1 Current approaches and opportunities

Overview of Flexibility based network management

Due to the increasing penetration of DERs in low voltage grids, new grid operation challenges like voltage deviations or overloading will be more common. Therefore, an automated tool is needed that will allow the DSO to operate the LV grid in an optimal manner, using the flexibility provided by DERs (or taking other corrective actions) to solve these forecasted problems, take advantage of the grid flexibility and operate under severe circumstances. This is the role of the flexibility-based network management engine. In the following paragraphs, several proposed and existing solutions about flexibility management are considered, such as research studies, platforms, tools and corporate solutions/proposals.

Literature Review - Flexibility based network management

Microgrids [8] provide a viable and localized solution to this challenge while removing the need for costly investments by the electric utility on reinforcing the existing electricity infrastructure. A flexibility-oriented microgrid optimal scheduling model is developed to coordinate the microgrid net load with the aggregated consumers/prosumers net load in the distribution network with a focus on ramping issues. The proposed coordination is performed to capture both inter-hour and intra-hour net load variabilities.

Development of flexibility cost maps [9] is a methodology which estimates the flexibility range of active and reactive power at the TSO-DSO boundary nodes (primary substations). It is based on solving several optimization problems, which use the optimal power flow (OPF) algorithm concepts. The novelty behind this methodology is related to the capability of estimating the entire perimeter of the flexibility area in the Power Quality (PQ) plan, i.e. estimates extreme points of flexibility. In practical

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terms, the flexibility area illustrates the PQ limits that the power flow at the TSO-DSO interface can assume through feasible activations of DER flexibility. The output is a set of flexibility areas corresponding to different maximum costs (i.e. a flexibility map) for each time instant of the forecast horizon.

Tools and Platforms for Flexibility based Network Management

Different tools and platforms, developed under internationally funded projects, are presented in the following table:

Table 4: State of the art tools and platforms related to flexibility-based network management

Tool/Platform	Short Description
Nodes Market Platform	NODES corresponds to an independent marketplace open to all flexibility providers and grid operators (flexibility requesters) with the main target to make the value of local flexible power resources available and facilitate the optimal use of flexibility in the grid (NODES MARKET LIMITED 2020, Whitepaper, NODES MARKET LIMITED 2020, case). NODES marketplace is investigated in different use cases: Engene, IntraFlex, FlexLab, NorFlex and Mitnetz are some of them, each one using the NODES market platform for different purposes like grid investments, renewable curtailment, auto-rebalancing, availability of local flexibility to TSO for manual frequency response restoration etc.
EPEX SPOT Local Flexibility Market Platform	EPEX SPOT local flexibility market constitutes an open and voluntary platform developed to resolve mostly market-based congestion management issues induced by intermittent renewable energy sources. This flexibility market platform centralizes local flexibility offers with critical physical impact for the TSOs and DSOs, helping them to address grid congestions.
GOPACS/IDCONS Local Flexibility Market Platform (ETPA Market Platform)	GOPACS is a platform developed for grid congestion management issues' mitigation and is based on IDCONS (Intraday congestion spreads) product. It was initially developed to investigate the flexibility assets coming from small-scale energy resources and in parallel provide the distribution grid operators with innovative congestion management tools. Currently, is in operational use in Netherlands by Dutch TSOs/DSOs.

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Piclo Flexibility Marketplace (Piclo Flex)	Piclo Flex is an independent marketplace for online flexibility trading, currently active in the UK. It has been developed with the main scope to standardize and facilitate transactions and flexibility procurement coordination by DNOs (Distribution Network Operators) and reduce the need for grid reinforcement. Piclo's target is to address use cases like grid reinforcement deferral in constrained areas where long-term demand forecast remains unknown, abnormal network conditions management and rural networks improvement.
INTERFLEX (InterFlex 2018)	The project implemented this system in diverse demonstrators (France, The Netherlands, Sweden, Germany, Czech Republic), with the aim of allowing DSOs to obtain flexibility at local markets for grid management optimization purposes.
DRIvE (DRIvE s.a.)	The DRIvE Project promotes the creation of a flexibility platform where several EMSs for residential and tertiary buildings interoperate among them to allow DR at the distribution network. The demonstrator, located in the Netherlands, consists of: 16 households, with each house having connected to a 2kW heat pump, a 200l hot water buffer, a 7kW PV installation, and a 7.8kWh battery A 220kW district BESS
SmartNet (SmartNet Project 2018)	SmartNet Project seeks to provide optimum coordination among TSOs and DSOs by means of comparing possible architectures, as well as the information interchange for several purposes: Acquisition of ancillary services, such as reserve and balancing, congestion management and voltage balancing control. Monitoring flexible load and distributed generation upon local and central power systems' request. The aim of this project is to develop a platform which will serve to perform ad hoc simulation for modelling the three layers: physical layer, bidding and dispatching layer and market layer, that will serve to evaluate how impactful DERs operation will be in terms of: Dispatching Market layout and sequencing Signals exchanged among TSOs and DSOs ICT inquiries Legal connotations

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Brooklyn Microgrid	Brooklyn Microgrid (BMG) is a community-driven initiative that began in April 2016 when the first peer-to-peer energy transactions were allowed (Brooklyn Microgrid 2019). BMG was created by parent company LO3 Energy to introduce the concept of a communal energy network in which residential and commercial users can buy and sell renewable energy, which is generated locally. BMG is a network that connects people in New York City who own solar arrays (prosumers) with people who are willing to purchase local solar energy (consumers). Solar energy transactions through BMG support the local economy and result in the reduction in greenhouse gas emissions. Moreover, BMG allows users to control where their energy is sourced.

Flexibility based Network Management - HEDNO's approach

In HEDNO, flexibility management is mostly an operational procedure and not a data-system based mechanism. The desired flexibility is achieved through Intermittent Load in collaboration with IPTO. IPTO contacts the Network Development and Operation department of every region in order to isolate the loads. HEDNO then executes the order. It is also mainly done by phone.

Flexibility based Network Management - CUERVA's approach

In CUERVA, there are not currently any automated procedures to manage DER flexibility to mitigate network issues. The following table intuitively summarizes CUERVA's proposal and suggested requirements regarding Flexibility based Network Management.

Table 5: CUERVA's proposal for flexibility-based network management

	Description
Prerequisites	a complete Grid model, weather monitoring service connection, LV Equipment technical specification (batteries, PV, thermal), Data Repository: smart meter data available for 100% of connected clients with minimum 1h frequency, (power, voltage) and real time data on the transformers (LV side) per line & per phase (voltage, intensity, power),

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	a way of simulating FSPs available flexibility. It can be done from real profile data of the DER with minimum 15 min frequency
Flexibility Users	Flexibility Service Providers (FSPs), whether they are individual prosumers/DERs or represented through an aggregator or any other type of DERMS (Distributed Energy Resources Management System). FSPs will provide at least the following information to the DSO: Type, Location, Meter Id, Current state (power, perhaps SOC for batteries/EVs), Available Flexibility and price, and activation codes. Flexibility Consumers, DSOs, acquiring flexibility for grid management services
Categories of DSO's functional building blocks for Low Voltage grid management	**Grid analysis and monitoring function:** will provide visibility to the operator about the current status of the LV grid and its forecasted status. The forecast should range from the next 15 minutes to next 1 to 2 hours. The following metrics must be monitored: V, I, P and Q at the feeder header level of a secondary substation. **Congestion alerting function:** will make use of these combined information to raise alert warnings about possible congestion, phase unbalances or voltage problems on the monitored grid. **Grid cure function:** Given an alert, this function decides upon the optimal preventive solution to the operator, considering the flexibility provided by the DERs and the possible corrective actions.
Functional building block evaluation scenarios	**A centralized or total control scenario**: In this scenario, the DSO has full control and visibility of the flexibility provided by any FSP registered on the grid. Commands can be issued to any FSP in near real time, and it is assumed that the DSO will have all the flexibility reported by the FSPs immediately available. **A market-based scenario**: In this scenario, FSPs report their available state, flexibility and the price they require in order to stay below a specified power limit to the Assets Registry. The DSO uses this information in the Grid Cure function, to decide upon the optimal actions (activation of flexibility or DSO corrective actions). If flexibility is activated, the exact quantities will be derived in a market-based fashion, based on the prices registered by the FSPs in the Assets Registry. Essentially, this scenario tries to establish the agreements of the centralized scenario close to real-time. Instead of assuming them to be in place, they are negotiated on the fly. The interfaces needed are simple. DSO -> market: express needs of flexibility and willingness to buy AGG -> market: express willingness to sell flexibility Then, the market clearing algorithm clears the market and informs the participants of the result. The DSO can then simply activate the contracted flexibility.

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Overview of DSO-TSO common operational scheduling

The other management engine, whose existing solutions are presented in this chapter, is the DSO-TSO common operational scheduling. This engine falls into the larger category of the TSO/DSO coordination. DSO and TSO cooperate in various fields in order to ensure the secure and reliable operation of the electricity system and network as well as the electricity markets. In the following paragraphs, significant studies about TSO/DSO coordination that have been proposed in literature are considered. Then, a series of EC funded projects that aim at the coordination of Greek DSO-TSO paradigm between IPTO (Greek TSO) and HEDNO (Greek DSO) are described. Finally, existing solutions of the Greek DSO-TSO paradigm are examined.

Literature Review - DSO-TSO common operational scheduling

The Day-ahead operation planning [10] concept is used to handle this issue at the stage of day-ahead operation planning and proposes a concept of smoothing the power profiles at transmission–distribution (T–D) interfaces by the use of DERs**.** The concept assumes that each Distribution System Operator (DSO) creates a bid of several possible 24-h smoothed power profiles at its T–D interface for the next day and submits that to his Transmission System Operator (TSO). Subsequently, the TSO solves the extended Unit Commitment (UC) problem to specify not only the commitment and dispatch of conventional electricity sources at the transmission system level but also to choose one profile for each T–D interface to be realized on the next day.

In France [11], the TSO operates all HV networks while DSOs operate MV networks at 20 kV mostly and some 10, 15 and 30 kV portions. The boundary or *interface* between TSO and Enedis is located upstream the HV/MV transformers.

In this frame, the operational coordination between RTE (TSO) and Enedis (DSO) consists of:

- *Electrical system safety and security management*: load shedding measures on Enedis network requested by RTE (apart from automatic load shedding), real time transit limitation at the interface either via generation automatic decoupling (generation disconnection automatism) via or requests, reactive power management,

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- *Operation and control of all boundary equipment throughout their operational life*: works/maintenance planning (yearly, monthly) for all RTE works impacting Enedis; coordinated operation, monitoring and control,
- *Operation and control in real time and in OP, with a potential impact on the other system operator operation and control activities*: i.e. transit limits anticipated by RTE (e.g. by demand–response mechanism) and impacting Enedis operation and control; Enedis needs for load transfer from one primary substation to another either planned for works/maintenance/network optimisation, or unplanned in case of fault, (incl. specific request to RTE for MV networks parallel/loop operation),
- *Management of concurrent 'permit to work' in the same interface premises (primary substations).*

In the short term, RTE takes advantage of powerful OP tools (convergence) interfaced with supervisory control and data acquisition (SCADA) systems at national and regional levels and operating on day ahead – intraday timeframe. These tools participate in the demand/response balancing process, network operation optimization as well as its security and reliability. These tools are interfaced with performing forecasting modules (IPES) partly fed by Enedis SCADA (i.e. for MV connected DER).

The OP tools developed by Enedis are built around a comprehensive software package made of: (a) local power forecasts (consumption and generation) tools, (b) a simulation platform detecting constraints (transit, voltage, protection plan issues, contractual thresholds overshooting etc.) and electrical system weakening at various time frames (ranging from two years in advance to few minutes before real time), and (c) optimization tools which aim at:

- *works planning optimization*: identifying the optimal works periods inducing the least impact on DER generation (what also reduces penalties for Enedis), allowing the feeding of all end-customers in the most reliable conditions,
- *operation optimization*: identifying the optimal internal and external levers combination and schedule that allows to alleviate constraints (technical, contractual and financial).

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TSO/DSO Coordination - EU funded Projects towards Greek Paradigm

IPTO and HEDNO cooperate, under research projects (CROSSBOW, COORDINET), in common demonstration sites. In the following table, a series of EU funded H2020 projects is presented (completed and under way) which illustrates the technical efforts that have been made so far towards the coordination of the TSO and DSO in Greece.

Table 6: EU funded H2020 projects involving Greece, related to TSO-DSO coordination

EU funded projects	**Short Description**	**Interesting Points**
SmartNet [12]	SmartNet was an EC research project that investigated how the TSO and the DSO could interact in order to acquire ancillary services (AS) from DERs connected to distribution networks. The types of acquired AS depend on the market model and may affect the operational schedule of the DSO and TSO. In the SmartNet project, five reference coordination schemes were operated in order to assess their performance. The schemes were simulated at international level (Denmark, Italy and Spain) with a 10-years operation time horizon in order to identify their functional benefits and the ICT cost that they carry. Moreover, the comparison among them revealed unique features of each AS market model and highlighted the dependence of a common DSO-TSO operation schedule to the type of AS market model.	The research efforts resulted in the following coordination schemes (Fig. 1): Centralized AS market model: The TSO contracts AS directly with DER owners connected to the DSO grid. The DSO can procure and use resources to solve local grid issues, but the procurement takes place in other timeframes (different from near real time, e.g. long term ahead) than the centralized AS market. Local AS market model: in this model DSO precedes TSO in AS contracting since TSO can acquire them only indirectly. Shared balancing responsibility model: The TSO transfers the balancing responsibility from the distribution grid to the DSO. The DSO has to respect a pre-defined schedule and uses local DER (obtained via a local market) to fulfil its balancing responsibilities. The pre-defined schedule is based on the nominations of the Balancing Responsible Parties (BRP), possibly in combination with historical forecasts at each HV/MV interconnection point. Common TSO-DSO AS market model: in this common flexibility market, TSOs and DSOs can contract DER directly by trying to minimize the total flexibility cost. TSOs and DSOs can both buy flexibility or sell previously contracted DER.

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		Integrated flexibility market model: here, the common flexibility market is expanded and third-party contractors (Commercial Market Parties - CMPs) are involved, besides TSOs and DSOs.
CROSSBOW	CROSSBOW will propose the shared use of resources to foster cross-border management of variable renewable energies and storage units, enabling a higher penetration of clean energies whilst reducing network operational costs and improving economic benefits of RES and storage units. The CROSSBOW results will be evaluated by 8 TSOs in Eastern Europe, grouped to form clusters that will validate each of the projects outcomes in at least three different countries, demonstrating in all cases how CROSSBOW tackles the transnational challenges faced by these TSOs.	The objective is to demonstrate a number of different, though complementary, technologies, offering TSOs higher flexibility and robustness through: a better control of cross-border balancing energy at interconnection points new storage solutions, distributed and centralized, offering ancillary services to operate Virtual Storage Plants (VSP) better ICT and Communications, e.g. better network observability, enabling flexible generation and Demand Response schemas the definition of a transnational wholesale market, proposing fair and sustainable remuneration for clean energies though the definition of new business models supporting the participation of new players (e.g. aggregators) and the reduction of costs.
COORDINET	The goal of this project is to investigate how TSO/DSO collaboration should manage and process the grid services in order to maximize the reliability and efficiency of the grid. The core of the CoordiNet project is summarized in the following key objectives: to find how the TSO/DSO coordination can enhance the electricity supply to the consumers in terms of reliability, cost and environmental safety. For this purpose, three large scale demonstrations in three different countries, namely Greece, Spain, and Sweden are implemented along with market participants,	The different identified classification layers are: NEED: “Which System Operator needs will be addressed?” In the classification layer describing the need to be fulfilled by flexibility, a distinction is made between local needs, central needs and the combination of both needs in a certain market set-up. Only needs which will be procured via a market-based approach need to be considered here. BUYER: “Which stakeholder(s) buy(s) the flexibility to answer a certain need?” The TSO, DSO and commercial parties are typical candidates to buy flexibility. In addition, more distributed buying models could sprout in a future time horizon, in

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	to commercialize the grid services through standardization and parameter setting, to utilize the created demonstration sites as a pivotal point for the TSO-DSO-Consumers cooperation platform. This will lead to the development of pan-European market where energy and grid services will be exchanged. It is profound that previously acquired knowledge should be exploited in order to learn from the past and avoid reinventing the wheel. For this reason, the proposed coordination schemes in the SmartNet project are applied and tested, along with alternative designs. Conclusions in SmartNet illustrate that the optimal coordination scheme does not exist and the most suitable one depends on the circumstances. Therefore, a mapping of coordination schemes and a common nomenclature is proposed by introducing classification layers that highlight the differences between these schemes.	which peers are actually the sole buyers (and providers) in the market. MARKETS: "How many markets are considered?" The third layer of the classification structure considers the number of markets. In the context of this report a distinction is made between a single market (i.e. 1), and the existence of multiple markets (i.e. >1) RESOURCES: "Does the TSO have access to DER?" If the TSO is allowed to procure flexibility services outside its own monitored area of control, i.e. at the distribution level, the coordination actions between the DSO and TSO will be different and are to be intensified. The process of going through the different classification layers, resulted in seven groups of coordination possibilities. The proposed coordination schemes are service-agnostic so that they can be applied to different services or even a combination of services, always maintaining a SO-viewpoint.

TSO/DSO Coordination - Greek Paradigm

Currently, there is no platform implemented for the DSO-TSO interaction about issues that involve day-to-day operations. As a result, a common DSO-TSO operational scheduling is still pending. However, there are ongoing technical efforts that aim to establish a communication link between the EMS of IPTO and the DMS of HEDNO, so a fully operational platform will be available soon. In the following table, an illustrative list of the fields of cooperation between Greek TSO and DSO are presented.

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Table 7: List of fields of cooperation between the Greek TSO and DSO

Field of Cooperation	Description
Signed Memorandum (HEDNO - IPTO)	A memorandum of understanding has been signed between HEDNO and IPTO. This includes the cooperation in the following fields: ● Planning and Development of Transmission and Distribution Systems ● System Restoration ● Congestion Management ● Real Time Data Exchange
Common Working Groups	Also, a lot of common working groups have been established in order to study issues of common interest like: ● Interconnection of Non-Interconnected islands ● Implementation of NC-RfG and DCC codes ● Establishment of National Energy and Climate Plans
Grid Planning	Grid Planning is coordinated between DSO and TSO. The scope of coordination is the secure, reliable and economic planning. DSO receives all necessary data from the TSO in order to set up its 5-year Network Development Plan (NDP). DSO provides the TSO with any data required for the design, the construction and the operation of a new connection points (HV substations) to the transmission system in order to ● Cope with increased demand ● Improve power quality ● Facilitate new DG connections All aforementioned projects are included in HEDNO 5-year NDP. DSO identifies any weak points on its network which are caused by the Transmission System's inadequacies, and proposes expansions of the Transmission System. All Common interest projects are examined by Regulatory Authority for Energy (RAE) in order to be and included in the 10 Year Network Development Plan of the TSO. TSO and DSO are exchanging information with regards to the progress of construction of projects of common interest. The TSO is also cooperating with the DSO with regards to the planning of new interconnections with the non-interconnected islands of Greece. In that case common working groups are formed in order to study the new interconnections.
Grid Operation	TSO and DSO are cooperating with regards to system operation. The scope of the coordination is the secure, reliable and economic operation of the power system. Coordination between TSO and DSO is mainly focused on the following areas: ● Load Shedding, which is performed by the DSO after request of the TSO, under critical System conditions. When the TSO issues an alert state the DSO shall be well prepared to perform load shedding if requested. ● Information exchange and TSO –DSO cooperation in power system restoration procedures ● Active power output limitation of DGs, when requested by the TSO. ● Maintenance Scheduling. The DSO is notified with regards to the maintenance schedule of the TSO. The DSO takes into account the maintenance schedule of the TSO in order to schedule distribution network maintenance. The DSO can also request modifications of the TSO's maintenance schedule. ● Protection coordination and interlocking arrangements. The TSO may request complementary protection on the distribution network

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	• With regard to Under Frequency Load Shedding, there is a coordination between the TSO and the DSO to set up the thresholds • The DSO can also request the contribution of the TSO in the maintenance and repair of high voltage distribution lines and HV/MV substations. When the DSO is about to perform switching actions that can lead to a load reduction higher than 10 MW on a connection point of the distribution network to the transmission system, then the TSO must be informed.
Settlement Processes	The TSO and the DSO cooperate in order to perform market settlements. More specifically: • the DSO calculates the a-priory shares of suppliers for the next month and sends the estimations to the TSO. • DSO provides the suppliers validated metering of all consumers connected to the distribution network. • DSO also provides the ex-ante calculations of consumers at regular intervals. • The TSO receives the ex-ante and the a-priori calculations of the shares of suppliers. • DSO calculates for each supplier the energy of its users without telemetering or with meter without hourly granularity. • DSO provides an estimation of the hourly energy for each supplier as well as of the corresponding charging and notifies suppliers and the TSO.
Data Exchange	Data is exchanged mainly with the sole TSO of the Greek market (IPTO). In particular, the DSO provides the TSO with all necessary information to set up the Network Development Plan. This information includes: • Load projections at every TSO/DSO connection point on a monthly basis • DER installed capacity • Network reinforcements for DSO needs (new connection points, i.e. HV substations) • Load transfer to new connection points • Load demand at the borders of TSO/DSO is automatically measured by the TSO. Both TSO and DSO have access to the measurements. The following data is also exchanged: • load profiles • load projections • DER measurements, • network topology • network development plan of the DSO • ten-year development plan of the TSO • maintenance schedules • ex-ante shares of suppliers (every month) • ex-post shares of suppliers (every six months) Other parties implicated in data exchange are the regulatory authority and the electricity supplying retailers. Secondary processes are also in place with public bodies and authorities, such as municipalities, government representative secretaries etc. All exchanges with electricity supplying retailers are performed automatically via dedicated software systems. The rest are handled manually, mainly by file exchanging via emails.

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2.2.2.2 Enhancements offered by SYNERGY

The flexibility-based network management and DSO-TSO common operational scheduling of the BaU of the SYNERGY stakeholders will be enhanced through the developments proposed in the project by:

- Supporting the transition to an automated coordination and interaction between the distribution and transmission network operators, where they would be in a position to optimally manage congestions and unbalances and operate their networks using the available flexibility
- Exploiting the forecasted flexibility data accessible to them through the SYNERGY platform and optimally scheduling the available flexibility to actively tackle short-term operational issues

2.2.3 Performance monitoring and predicitive maintenance

One of the main challenges when operating an infrastructure is to minimise the Operational and Maintenance (O&M) costs related to its exploitation. Fault diagnostic and predictive maintenance methods have been targeted in different research approaches during the last years, proposing different models and with similar aims: detect performance anomalies to reduce O&M costs, while avoiding premature degradation of the plants that would lead to a significant reduction of the energy generation. A continuous monitoring of the plant operation can also help to identify eventual faults, that would hamper the energy yield, provoking energy losses due to different causes: soiling, module hot spots, etc. [13]. A recent research focused on the approaches, challenges and opportunities offered by PV predictive maintenance, stated that if issues related to PV performance are not detected nor unanticipated, the energy generation capacity of the plant, as well as the warranty of the different equipment would be reduced or even lost [14]. Hence, it seems crucial for the PV sector to provide an adequate preventive and predictive maintenance, seeking the energy maximization as well as lengthening the life spam of the installations.

2.2.3.1 Current approaches and opportunities

Among the methods employed by RES operators to carry out the preventive and predictive maintenance in PV plants, Bosman et al. [14] proposed the following classification: 1) Manual diagnostics, within which the traditional maintenance procedures are included; 2) Failure modes and effects analysis approach; 3) Machine learning and forecasting models; 4) Real-Time sensors.

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1. Manual diagnostics

These maintenance procedures include the conventional inspections and most frequent activities carried out in PV plants. Although they are effective to improve the preventive and corrective maintenance, they offer the lowest accuracy for predictive maintenance. Visual inspections to identify potential risks for the energy production, such as shade due to tree growths, or soiling for different causes (dust, leaves) are categorised within the manual diagnostics [15].

Infrared (IR) thermography is also included within the manual diagnostics. This can be done in the different devices installed in the plant. Drones equipped with thermal cameras are used for doing this inspection in PV modules in large plants, which might be used to identify hotspots at cells (Figure 3). Different research have assessed this method, stating the high accuracy for reporting these kind of anomalies, while having a greater cost than other maintenance procedures [16]–[19]. Its main advantage is the identification of failures otherwise almost imperceptible (Figure 3).

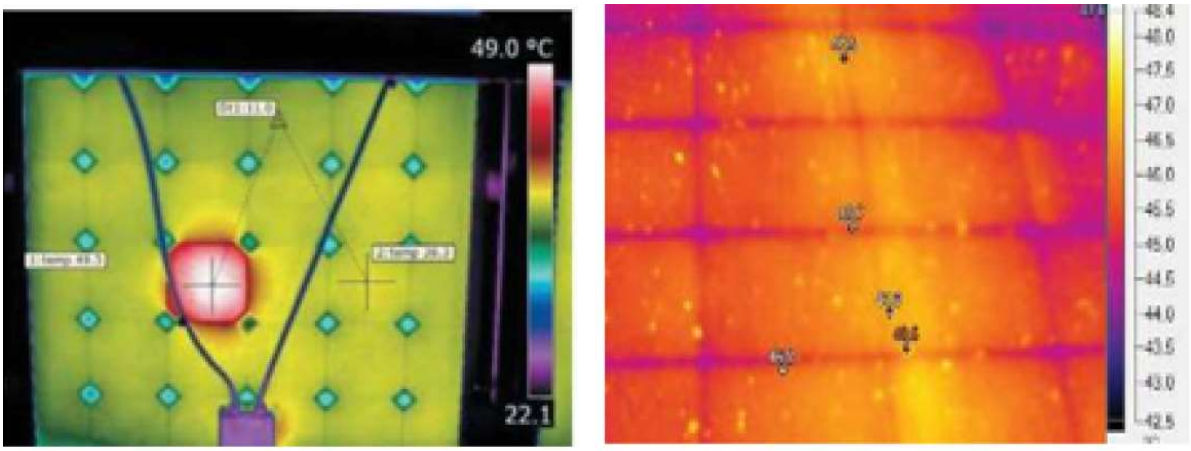

Figure 3: Images obtained from an IR inspection for cells anomalies and hotspots identification, respectively.

2. Failure modes and effects analysis

The failure modes and effects analysis (FMEA) are focused on identifying the devices used in PV plants with the highest risk of failure [14] These procedures have been reported as more accurate for failure identification when compared to manual diagnostics, while having a greater cost for deploying on the other hand. This could be either done by evaluating the energy losses, analysing the historical records of failures recognizing the devices with greatest failure probability, which is very unlikely of being available in most of the plants or considering the equipment exposed the most to specific climate conditions. For such purpose, different indexes could be defined, such as the status of health (SoA) or

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the risk priority number (RPN), which indicates the likelihood of failure of the different components by defining a risk failure scale [20]–[22].

Another research exploring the FMEA was focused on developing a quantitative analysis of the different equipment in 63 PV plants, stating that the highest failure probability was found in monitoring devices, communication systems, inverters and electric grid, being the failure rate per kW higher in small PV plants, doubling this index in plants smaller than 750 kW when compared to large PV plants [23].

3. Machine Learning and Forecasting

Olivencia Polo et al. [24] introduced a methodology focused at inverter levels, that identified faults or failures based on a performance deviations respect to the expected outputs in devices encompassed within areas with similar climatological conditions, whose performance should be almost identical. Hence, by analysing numerous statistical indexes it was possible to find a performance irregularity (fault or failure).

Talayero et al. [25] presented a detailed analysis of eight photovoltaic (PV) plants revealing improvements on the monitoring system and the maintenance procedures. With data monitored at eight PV plants, the performance ratio (PR), defined as the ratio between the actual and theoretical energy production, was estimated. Assessing this index and analysing each case, different loss causes were identified, such as losses due to vegetation, inverter failure or tacking system failure. Staying within this research line, Talayero et al. [26] developed a diagnosis failure method based on performance monitoring. More specifically, the algorithm used multivariate linear regression and machine learning, inputting data measured at the PV plant and estimating the energy output of the inverter. This estimation was then compared with the actual measurement and any potential failures detected if any anomalies were detected between the real and expected production.

Polo et al. [27] developed a logical decision tool based on artificial neural networks (ANNs), which used operational and environmental conditions data. Focused on the comparison between the cumulative actual energy output measurements and the expected output within a defined time range, the tool used reliability models developed according to the available amount of failure data, in order to detect early degradation due to power inverters and solar trackers failures.

Another interesting method for fault detection in PV systems using statistical and machine learning proposed a simple model based on just an equation, which used irradiance and panel temperature to estimate the power production and compare it with real measurements at plant levels [30]. In order

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to measure the accuracy of the equation model, it was compared with an ANN. As the accuracy results obtained were within an acceptable range, even improving the results of ANNs, the model was considered as valid for fault diagnostic. Moreover, it is supposed to be a much more simple and computational cheaper method. The implementation and validation of the method in a real-scale 120kW plant showed a fault detection rate over 90%.

Chang et al. [28] proposed the use of artificial intelligence techniques for improving the Operation and Maintenance costs in more than 150 plants with a production capacity of 54MW. The model applied artificial neural networks, which were fed by environmental and production data (radiation, current and voltage), predicted the power production and was able to detect fault and/or failures in the system. The results showed how this approach achieved an improvement of 0.16 kWh/kWp/day (4.7%) at plants using it.

De Benedetti [29] developed a novel methodology, which targeted the detection of current and potential anomalies within PV plants, helping to avoid severe failures, hence reducing the operational and maintenance costs of the system. The method used ANNs for predicting AC power production with only two explanatory variables, irradiance, and panel temperature. Thereafter, the model output values were compared and evaluated with live trend data, detecting potential anomalies and generating daily predictive maintenance alerts. The model showed predictive detection rates greater than 90%.

4. Real-Time sensors

The last category identify by Bosman et al. [14] combines the monitoring sensors responsible of tracking the PV plant performance and the Internet of Things (IoT). This combination has been proposed in some research as real-time sensors responsible of evaluating the quality control issues at the plant. Different solutions have been proposed during the last years, including meteorological, thermal and electricity off-the-shelf sensors, connected to a microcontroller where fault detection algorithms could be implemented. Comparing the estimated energy generation to the actual measurements, a set of errors thresholds could be outputted [30]–[34].

2.2.3.2 Existing solutions

Under this subsection, a review of the common functionalities – from a technical perspective – present in solutions available in the market (in line with activities reported in D10.5 SYNERGY Market Radar v1) is presented, which establish the baseline that, in addition to the requirements and use cases reported

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in D2.1 End-user and Business requirements analysis for big data-driven innovative services and ecosystems v1, serves as the basis to the design of the Performance Monitoring, Forecasting and Predictive Maintenance for large-scale RES plants application presented under section 3.3.

- Evaluate the performance of each plant, not only based on the technical specification of the vendor and local data, but also based on the behaviour of plants using similar components.
- Introduce new approaches for predictive maintenance of PV plants focused on the failure analysis of the different components in other installations and the identification of reliability indexes.
- Optimize the bidding functions for RES operators, identifying portions of the energy produced that could be included in long-term PPAs with energy retailers.
- Optimize the participation of RES stations & Demand assets in the Wholesale Market through two Market Agents acting as RES aggregator and DR aggregator respectively.

2.2.3.3 Enhancements proposed by SYNERGY

The performance monitoring, forecasting and predictive maintenance will be enhanced through the developments proposed in the project by:

- Allowing the proactive diagnosis of equipment faults and their characterization, enabling the continuous monitoring of key power quality indicators, assessing the probability of fault occurrence and providing more accurate active/ reactive power forecasts, based also on the objective assessment of the PV plant assets' status and health.
- Supporting transition from preventive-based maintenance (regular scheduled assessments) to predictive-based maintenance, where collected data is used to anticipate failures and schedule maintenance operations accordingly.
- Feeding into Retailers, DSOs and TSOs systems high-value information for either optimizing green power exchanges/ trading (retailers) or improving short-term operational scheduling.

2.2.4 Asset management optimization

Under this subsection, a review of the common functionalities – from a technical perspective – present in solutions available in the market (in line with activities reported in D10.5 SYNERGY Market Radar v1) is presented, which establish the baseline that, in addition to the requirements and use cases reported

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in D2.1 End-user and Business requirements analysis for big data-driven innovative services and ecosystems v1, serves as the basis to the design of the Asset management optimization application presented under section **¡Error! No se encuentra el origen de la referencia.**.

- The particularities of the utilities targeted by this solution makes it usual that solutions are offered both as on premise (stand-alone) and as SaaS on cloud solutions. This approach facilitates fulfilment of requirements provided by organizations with different sizes and data-management policies
- User interfaces of the solutions are provided in the form of a website, thus allowing access to the asset management applications from different contexts and locations
- Most asset management solutions follow a modular approach, even plugin-based, that allows the solutions to be adapted to the specific requirements of its customers
- Management solutions include databases for handling the information of the operational assets, including technical and physical characteristics, geolocation and hierarchical relationships
- Considered data sources include both offline and online data. With regards to online data, integration with SCADA and other online monitoring systems is considered. Retrieved data is merged with data/parameters coming from individual asset documentation as part of its processing
- All processed data available from the assets under maintenance is usually reduced to some kind of score (*asset health* or *asset loss of life*) which is employed to reflect the asset status to maintenance operators in a comprehensive manner
- If real-time data is available, this is usually used to provide early equipment failure warnings on a near real-time basis (stream processing of this data is performed)
- Risk impact matrices are used to prioritize management tasks, according to the asset state calculated by the solutions

2.2.4.1 Existing situation

In the existing situation (BaU operations mainly related to the maintenance of the grid assets, as reported by DSOs and TSOs), preventive and corrective maintenance operation prevail. As described in detail in the following sections, the maintenance operations are currently governed by the actions described in the corresponding technical documentation of the assets (which state recommendations

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on the scheduling of revisions) and by actions triggered by the actual occurrence of faults. This approach is mainly motivated by the lack of data (only the most critical assets do usually have the necessary sensors and telemetering systems in place), and measurements required to assess the health status of the equipment are usually manually taken by specialized maintenance personnel.

Distribution grids asset maintenance (BaU by HEDNO)

HEDNO's Network maintenance scheduling and maintenance operations are performed in such a way as to minimize the impact on the operation of the Network and any Power Outages to the Users. The maintenance of the equipment of the Network and its planning is carried out according to the instructions of the equipment manufacturers, the internationally valid standards, the Instructions of the Network Operator and best practices, taking into account the condition of its components (equipment age, fault and maintenance history), their technology, their operating and charging conditions, their importance for the safe operation of the network and the power supply of the Users, as well as the possibilities of alternative power supply in case of interruption of their operation.

Regarding the maintenance of critical assets (e.g. power transformers, sectionalizers, reclosers, wooden poles, etc.), the following applies in summary:

Preventive maintenance (maintenance at regular intervals) is applied, regardless of the occurrence of anomalies or damage to the components of the equipment, on critical assets of the network (reclosers, sectionalizers, voltage regulators etc.), based on the manufacturer's instructions, available equipment experience (e.g. fault history), number of operations, strain (e.g. heavy loads), technology (e.g. oil arc fading or in the vacuum), the importance due to location, the possibility of alternative supply, etc. For the rest of the connection and protection elements (fuse disconnectors, 1P and 3P disconnectors), their mechanical devices should be preventively maintained every four (4) years, according to Distribution Directive No9 [35]. Preventive maintenance also includes the maintenance of wooden poles, which is first carried out 15 years after the initial installation of the pole and then every 10 years (Distribution Directive No10 [36], "Procedure for Carrying Out Maintenance Work and Utilization of Dismantled Wooden Poles") but also the pruning and vegetation trimming works around the connection and protection points, which are carried out on an annual basis (Distribution Directive No 9). Preventive maintenance limits the occurrence of damage, minimizing any abnormalities and their consequences.

Focused maintenance is applied to those items, which were found - from the inspection - to be in need of maintenance. The objective of the inspection is to repair or replace these components in order to

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prevent damage and consequent interruptions. The networks are inspected on an annual basis and according to the observations that result from the inspection, the necessary maintenance or interventions are performed to remove the damages or anomalies found, such as replacement of cracked insulators, tightening of loose connections, tightening of tension, keeping safety distances, pruning of trees, oil replenishment in a terminal box or in a Transformer, replacement of dangerous poles etc. Apart from visual inspection, in recent years the annual inspection of the network is performed using also thermal cameras (and more recently even drones), in order to detect those elements of the network that could potentially cause damage.

In parallel with the above, HEDNO, following international practices, is gradually switching to modern methods of predictive maintenance (Predictive Maintenance (PM) or Condition-Based Maintenance (CBM)). Predictive maintenance consists of the use of modern technology methods for monitoring, examining and assessing the status of network components, in order to detect any evolving anomalies and repair them, before they cause extensive damage to the network. Predictive maintenance can reduce maintenance costs since maintenance work is performed only when it is really needed. It can also increase installation's reliability and customer satisfaction by reducing scheduled and non-scheduled outages. Finally, it can postpone new investments by making the best use of the existing equipment. Such predictive maintenance methods used by HEDNO are for example the use of thermal imaging devices by means of infrared light (thermal cameras) for the inspection of Network elements, the introduction of devices for measuring mechanical resistance of wood (resistographs) for the inspection of wooden poles, etc. Technical leaflets and instructions have been issued by HEDNO for these new technologies, with the latest being ΔΔ/125/09.01.2020, which concerns the use of resistographs, while from time-to-time training seminars are held for HEDNO personnel.

Finally, HEDNO performs corrective maintenance that coincides with the occurrence of damage or destruction of the components of the Network. This is applied to elements for which preventive maintenance is considered unprofitable, e.g. due to the need for long power outages to complete their maintenance.

The Maintenance activities of the Network entrusted to Contractors are those related to the pruning of trees near the Distribution Network and the deforestation of vegetation under critical elements of the Network. In all HEDNO Areas, tree pruning and deforestation contracts are carried out, which are mainly for 2 years. In case their budget is exhausted before the end of the 2-year period, the Regions are requested to increase the amount by 50%. The increase also applies for the duration as long as the budget has not been exhausted.

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For the inspection and maintenance of wooden poles (with the use of both the classic methods and resistographs), there's an ongoing tender by HEDNO's Materials, Procurement & Transportations Department. This tender is at the stage of evaluation of Financial Bids for the 45 Regions of HEDNO for which eligible bids were submitted. For the remaining 14 HEDNO Regions, Materials, Procurement & Transportations Department will hold a new Tender.

The inspection of the Network is mainly performed by HEDNO crews, however in recent years, in the HEDNO Areas where the personnel has been reduced, contracts are concluded locally.

Transmission grids asset maintenance (BaU by IPTO)

At the moment of writing IPTO's Maintenance Practice is nearly all offline and time-based. This means that the maintenance of an asset is performed according to a time schedule that is dictated by the manufacturer of said asset and it is done by taking data on the spot at the time of maintenance. A relevant check list is filled that gives an evaluation of the asset's health status and sets the mode of the maintenance.

IPTO is slowly moving towards a Condition-based Maintenance regime and is installing assets with online data acquisition capabilities. The prospect of Predictive Maintenance and any effort towards that way is of great interest to IPTO.

For IPTO the main assets that is vital to service and maintain efficiently are autotransformers, automatic switches and reactors and the general faults that the maintenance department is trying to prevent is thermal and dielectric.

Table 8 Transmission Grid main assets under maintenance and usual offline measurements

Grid asset	Usual offline (manual) measurements
Autotransformers	Resistance, insulator resistance, tan delta, transformation ratio, followed by oil sampling, visual and mechanical inspections
Automatic Switches	Separation resistance, open-close and close-open timing, separation length, current on separation, followed by visual and mechanical inspections and oil sampling if it uses oil as an insulator or gas quality if it uses gas
Reactors	Resistance, insulator resistance, tan delta, followed by oil sampling, visual and mechanical inspections

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2.2.4.2 Enhancements offered by SYNERGY

The maintenance operations in the BaU for both distribution and transmission grids will be enhanced through the developments proposed in the project by:

- Facilitating the evaluation of the health of assets by providing maintenance staff with means to automatically assess the status of the assets based on the reported data and the results of previous inspections, thus reducing the learning curve of the dedicated personnel
- Support transition from preventive-based maintenance (regular scheduled assessments) to predictive-based maintenance, where collected data is used to anticipate failures and schedule maintenance operations accordingly
- Increase grid status awareness by anticipating cascading effects of alerts and issues reported in real-time by the corresponding grid management systems

2.3 Relevant use cases and actors

Below, a brief reference is made for each UC pertinent to the scope of this deliverable, containing the title and ID as well as the actors involved.

ID	Title	Actors
UC_5_1	Simulation-based network performance assessment	DSO, TSO, Retailer, Aggregator, Flexibility Service Provider
UC_5_2	Optimized sizing of network assets	DSO, TSO, Retailer, Aggregator, Flexibility Service Provider, Public Authorities
UC_5_3	Network flexibility availability estimation (short-term)	DSO, TSO, Retailer, Aggregator, Flexibility Service Provider, Prosumer
UC_5_4	Collaborative (D&T) Network flexibility activation scheduling	DSO, TSO, Retailer, Aggregator, Flexibility Service Provider, Prosumer, Consumer

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ID	Title	Actors
UC_5_5	Performance monitoring of PV plants status and assets' health.	PV owners, RES operators, Facility Manager
UC_5_6	Predictive maintenance of PV assets	PV owners, RES operators, Facility Manager
UC_5_7	Enhanced monitoring of status and health (including VR navigation) of network components	DSO, TSO
UC_5_8	Knowledge-based preventive maintenance scheduling for network assets	DSO, TSO
UC_5_9	Optimized energy bidding and output sharing in PPAs	PV owners, RES operators, Facility Manager, Retailer/RES aggregators, DR and flexibility aggregators.
UC_5_10	Optimized energy bidding and output sharing in wholesale.	PV owners, RES operators, Facility Manager, Retailer/RES aggregators, DR and flexibility aggregators.

The following table provides a matrix linking each energy application pertinent to WP5 with each one of the UCs presented above.

App Category	Application	Use Case
Infrastructure Sizing and Grid Planning Application	Network Performance Assessment Engine	UC_5_1
	Network Assets Sizing Engine	UC_5_2

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App Category	Application	Use Case
Flexibility based Network Management and DSO-TSO common operational scheduling Application	Flexibility Based Network Manager	UC_5_3
	DSO-TSO Common Operational Scheduler	UC_5_4
Performance Monitoring and Predictive Maintenance Application	Enhanced Performance Monitor	UC_5_5, UC_5_6
	Fault occurrence inspector and maintenance optimizer	UC_5_5, UC_5_6
	Operational scheduling optimizer	UC_5_9, UC_5_10
Asset Management Optimization Application	Network Asset Health Estimator	UC_5_7
	Network Predictive Maintenance Manager	UC_5_8

2.4 Architecture and interface to the SYNERGY platform

The energy applications that will be developed within WP5 will be constantly interacting with SYNERGY Energy Big Data Platform and the AI Analytics Marketplace in order to acquire the necessary data assets and offer the information that produce back to SYNERGY Platform. In this context, the following interactions between WP5 applications and SYNERGY Platform are taking place:

- Acquisition of stakeholders' data from the SYNERGY Platform through the API Gateway.

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- Deliver the application' generated data to the SYNERGY Data & AI Marketplace

Configuration of data analytics processes in the Analytics Workbench and execution of these processes in the SYNERGY Cloud Infrastructures or in the On-Premise Environment.

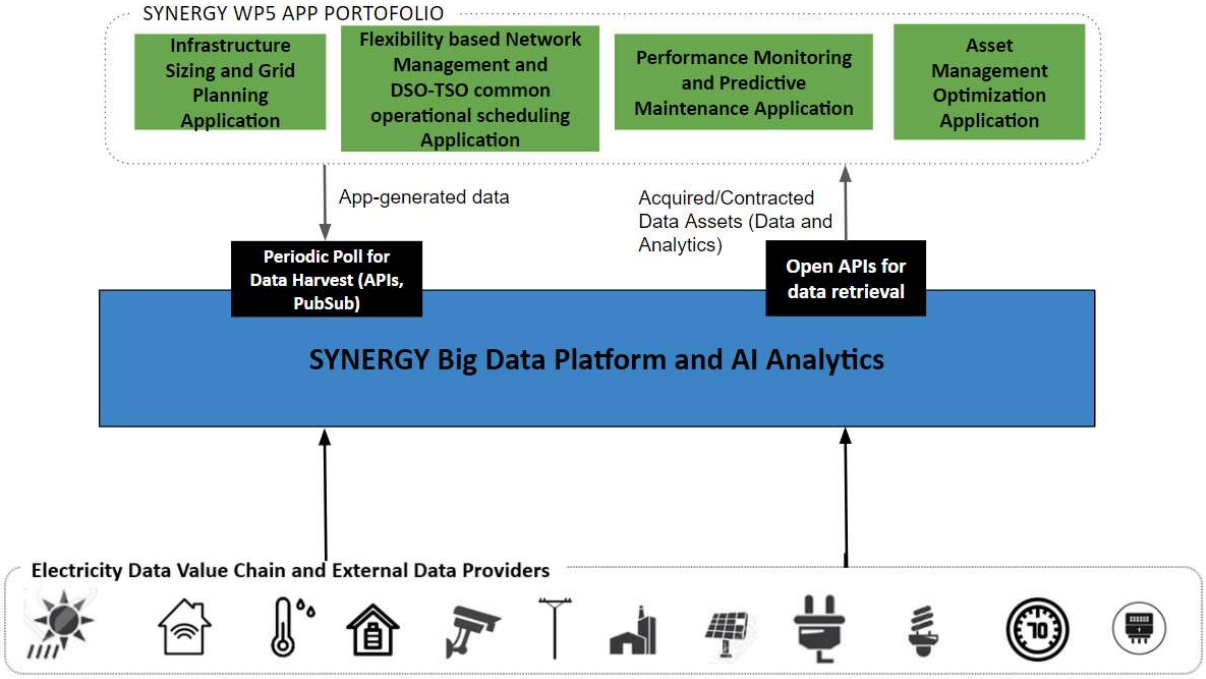

Figure 4: High-level architecture between WP5 applications and SYNERGY platform

Figure 4 illustrative presents the aforementioned interactions. In the following sections, these interactions are described in more detail:

Data acquisition:

The applications within the frame of WP5 need to perform the Data Search and Sharing functions in order to retrieve the specific data and analytics that are necessary for their operation. The Data Search and Sharing functions refer to the required data retrieval pipelines that have to be made by the applications in order to acquire the expected input. After the acquisition of the data assets, applications can process or store them locally if it is prescribed by data asset contracts.

The data acquisition from an energy application is made as a query process. This is a pre-defined retrieval query which is set by the application within the Data Search Service Bundle of the SYNERGY Platform and it is called when a specific data asset is needed from the SYNERGY platform (i.e. Cloud Platform, Secure Experimentation Playgrounds, On-Premise Environments). The configuration of this

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query requests the application to define some parameters, then the query properly filters the incoming information and finally returns the matching results.

The components of WP5 will communicate with SYNERGY Platform through the SYNERGY's provided API Gateway. The applications and components of WP5 will be able to connect to this API with authorized access and then harvest the required data assets, either input data for their operation or advanced data analytics from the respective organisation's Secure Experimentation Playground. The API Gateway acts as an intermediate node that routes the data requests to its appropriate destination, collects the requested data and delivers them to the application. Applications only have to provide the predefined parameters to the API, e.g. single/multiple dataset, active contract, data analytics generated from particular application, etc., to retrieve the required data. This form of abstraction facilitates the communication between WP5 applications and the SYNERGY Platform.

Data provision

The SYNERGY Platform provides data assets, that belong to other electricity data value chain stakeholders, to the WP5 applications, which in this case are considered as data consumers, by performing the following three phases of interaction:

1. the data consumers are searching the data assets that they need via the **Data Matchmaking Service Bundle,**
2. then, data consumers retrieve the aforementioned data assets using the **Data Sharing Service Bundle** available through the Data and AI marketplace,
3. after the retrieval of data assets through the SYNERGY Data and AI Marketplace, the applications are supposed to use the acquired data assets to perform advanced analytics in the SYNERGY Analytics Workbench and Execution Service, and finally, upload the data assets that they will produce through the Data Collection Service Bundle and the creation of respective **Data Check-In jobs**.

When a WP5 component acts as a data asset provider, it has to execute all the mandatory steps to collect the information regarding the data they intend to deliver to the SYNERGY platform. Upon accessing the SYNERGY platform, a new data check-in job is created. There are several pre-processing steps to follow, such as Mapping and Transformation, which is a compulsory step, or Cleaning, Anonymisation and Encryption, that are optional steps. The sequence in which these mandatory steps are executed is the following:

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1. Initially, the configuration phase of the data check-in job, the data asset providers have to define the data ingestion step along with the way the data will be collected,
2. Then, the mapping and transformation rules regarding their data have to be configured,
3. Consequently, the data cleaning rules have to be set and afterwards, proceed with the anonymisation step,
4. Finally, they need to configure the encryption rules.

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3 Specification of Applications

SYNERGY project is delivering a tool suite for network operators, called "*Asset Management Tool Suite*" composed by 4 applications:

- Infrastructure Sizing and Grid Planning Application
- Flexibility based Network Management and DSO-TSO common operational scheduling Application
- Performance Monitoring and Predictive Maintenance Application
- Asset Management Optimization Application

The user interface targeting distribution and transmission system operators will be provided in the form of a web-based UI. The particular stakeholders will register themselves in the *AM* tool suite, providing their identification, credentials and an identification token to gain access to the relevant datasets the particular stakeholder has available on the SYNERGY Platform (note: an active data asset contract that dictates the exact terms and signed in the SYNERGY Platform is a precondition for accessing the data).

The following sections provide a detailed view of the features, internal components, interactions and user interface of each one of these applications.

3.1 Infrastructure sizing and grid planning application

The application is comprised by a set of software components, each of those is dealing with its particular task. The components can be categorized with regard to the specific functionality they serve:

- **Data ingestion components**: Data providers publish data in the SYNERGY platform allowing the applications with associated permissions to access those data assets. Data uploads and data retrieval from stakeholders, third parties and applications are facilitated through the SYNERGY platform specific APIs and other suggested data retrieval methods provided by SYNERGY. The access and subscription to sets of data is facilitated through the issuance of appropriate contracts signed by the interested data requestors and data providers. Data requestors create relevant queries which contain the exact parameters for the data in need.

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Subsequently, data is stored in operational local databases for further utilization from the application's components if the contract's terms allow it.

- **Operational components**: These components refer to the tasks which fulfil the main functionalities of the application, such as the two specific engines of the app and their associated features. The infrastructure sizing and grid planning application aims to facilitate network operators to assess the status of their networks, including probabilistic assessments that estimate expected congestions on network equipment and therefore flexibility and capacity reinforcement requirements. The application consists of the network performance assessment engine which assesses the state of the network under certain test cases and the network assets sizing engine which facilitates the network operators to indicate planning requirements, upgrades on substation and lines and DER hosting capacity.
- **Interaction with other applications**: The Infrastructure sizing and grid planning application shall interact with other applications of the project and also with other applications of the same category. All interactions always happen through the SYNERGY platform. For instance, flexibility estimates and demand/generation forecasts calculated in WP6 apps shall be communicated to the Flexibility Based Network Manager to support the short-term scheduling decisions of the network operators.
- **Analytics components**: All algorithms related to data analytics, running on the core of the SYNERGY platform, for instance providing forecasts, clustering of data, pattern identification.

An overview of the application is provided in Figure 5, showing the application and its two operational components and the interactions with the SYNERGY platform and the associated stakeholders.

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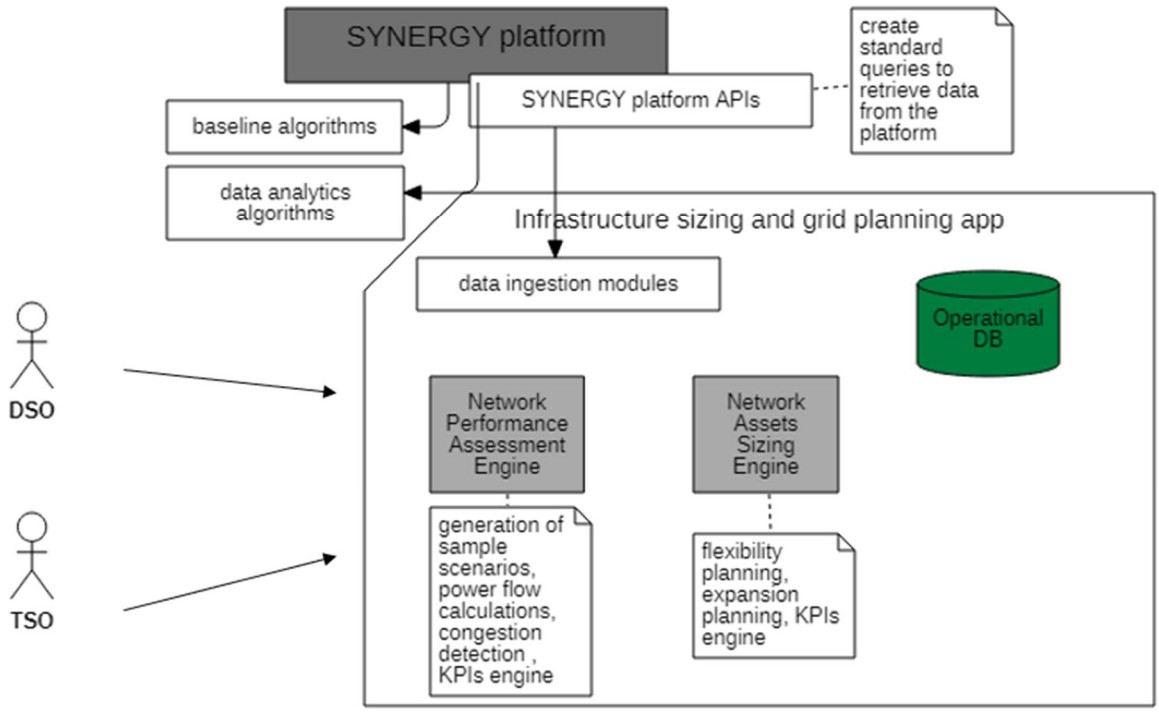

Figure 5: Infrastructure sizing and grid planning application

3.1.1 Component details

3.1.1.1 Network Performance Assessment Engine

The Network Performance Assessment Engine (NPAE) is responsible for the simulation of the operation of the network and incorporates all the appropriate functionalities to assess the state of the network in terms of reliability, performance, and power quality metrics.

The assessment involves the evaluation of the electricity network steady state aspects using power flow calculations. Congestion issues and operational constraints, such as voltage violations, line/transformer over-loadings are considered in the assessment. The simulation approach of the NPAE is static, which means that the dynamic behaviour of the power system elements is omitted from the analysis. The component involves the assessment of various operating conditions, incorporating the analysis of stochastic demand and generation profiles.

As depicted in the component diagram, main input data consists on the historical meter data of the network operator, anticipated penetrations , exogenous variables, such as weather forecasts and outputs from other SYNERGY applications such as short and long term forecasts.

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By processing the aforementioned inputs, different models will be configured and executed to produce the required results, such as power flow calculations. These results will be used to build the corresponding visualizations to be used by the network operator.

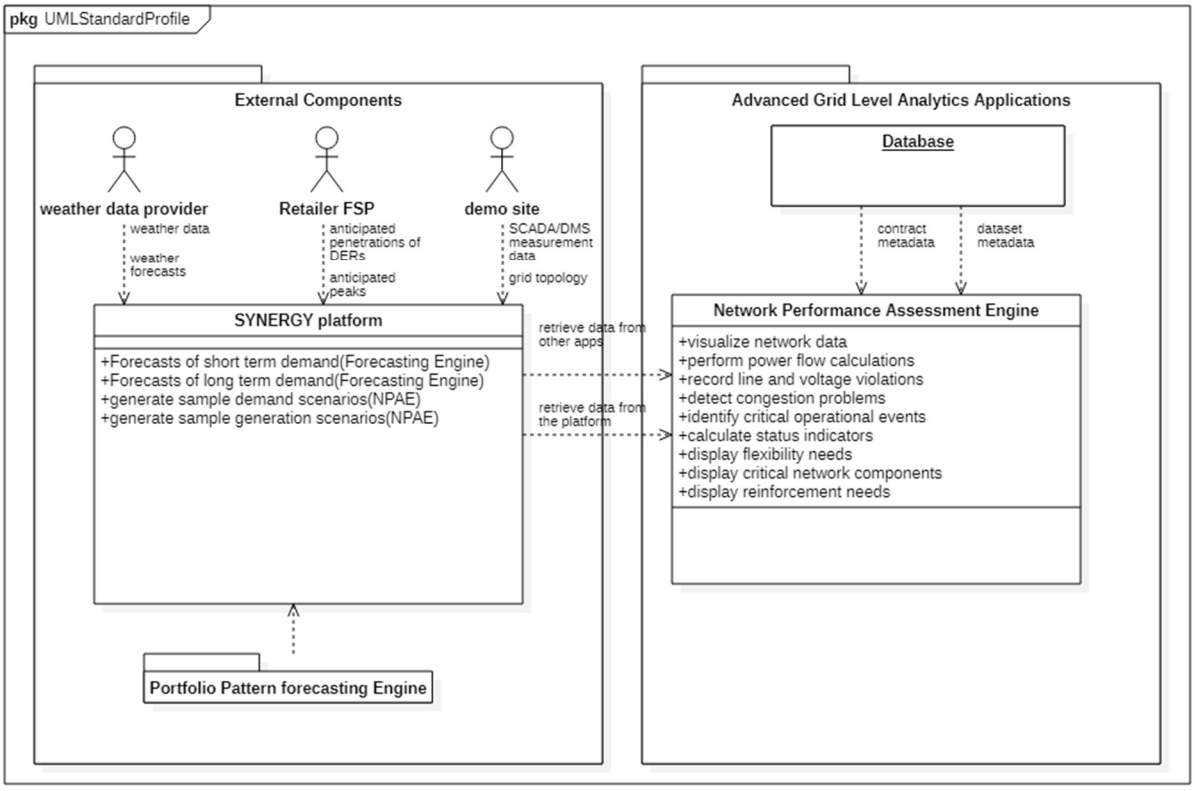

Figure 6: Network Performance Assessment Engine Component Diagram

More details on the features, data inputs/outputs and analytics to be performed by the component are provided hereby. The list of features offered by the Network Assessment Performance Engine, as initially have been described in D2.6, includes:

Table 9: Features of the Network Performance Assessment Engine

Feature	Description
NPAE_1	**Generation of demand and production scenarios**: The Network Performance Assessment Engine allows the integration of uncertainty aspects into the network analysis. Considering the integration of varying renewable resources and stochastic loads, uncertainty is represented by the generation of a finite set

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	of sample scenarios for the demand and production sources integrated into the network or by the inclusion of their probability distributions.
NPAE_2	**Power flow calculation**: The Network Performance Assessment Engine allows the calculation of the state of the system in normal operating conditions (possibly accounting also for the N-1 security criterion). Specific demand and generation snapshots can be studied, as well as seasonal time series profiles. The pf computation includes corrective and preventive control policies related to active power, reactive power, and voltage. The optimization shall include the minimization of generation cost of intact system state. A few fault scenarios ,such as specific transformer or line failures, shall also be studied.
NPAE_3	**Identification of critical operational events**: With the help of Network Performance Assessment Engine, the situations when load exceeds generation supplies (and vice versa) can be identified. Also, the estimation of probability of assets overloading (loading above the nameplate rating) can be calculated for estimated peak loads when the occurrence of peak load is higher than the assets capacity. In addition, critical nodes and lines of the infrastructure can be determined. Critical operational events that can cause DER curtailment, load shedding, reserve deployment can be identified, and critical loading situations shall be identified.
NPAE_4	**Detection of congestion problems**: The Network Performance Assessment Engine allows the investigation of network constraints violations. The capacities of the lines and the substations are checked. If the values are larger than the maximum allowed capacities, overloads are recorded. Similarly, over-voltages and under-voltages are also recorded, and a list of grid alarms can be issued.
NPAE_5	**KPIs calculation - basic status indicators**: The status indicators give an overview on the service efficiency of the network operation. In addition, this specific feature will indicate flexibility needs, reinforcement needs and the related cost benefit metrics. The Network Performance Assessment Engine shall provide a KPIs visualization feature.

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NPAE_6	**Data ingestion:** Allow and build interaction with the SYNERGY platform to access any data, measurements, grid models stored in the platform.

The list of input data of the Network Assessment Performance Engine is presented in the following table.

Table 10: Network performance assessment engine data inputs

Historical TSO demand	**Time series of energy demand at the relevant TSO areas (substation and feeder level)**
Expected update rate	Daily
Coverage	All customers of portfolio (or aggregated per substation) Minimum period of 1 year
Resolution	Hourly Per customer/ per substation
Historical DSO demand	**Time series of energy demand at the relevant DSO areas (substation and feeder level)**
Expected update rate	Daily
Coverage	All customers of portfolio (or aggregated per substation) Minimum period of 1 year
Resolution	Hourly Per customer/ per substation
Historical TSO generation	**Time series of energy generation at the relevant TSO areas (substation and feeder level)**
Expected update rate	Daily

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Coverage	Minimum period of 1 year
Resolution	Hourly
Historical DSO generation	**Time series of energy generation at the relevant DSO areas (substation and feeder level)**
Expected update rate	Daily
Coverage	Minimum period of 1 year
Resolution	Hourly
Historical SCADA measurement data	**Time series of SCADA/DMS events and measurements of P,Q,V,I at the relevant HV/MV substations**
Expected update rate	Daily
Coverage	Minimum period of 1 year
Resolution	Hourly
Weather data	**Time series of weather-related data**
Expected update rate	Hourly
Coverage	Relevant locations Minimum period of 1 year
Resolution	Hourly
Anticipated penetrations of EVs, RES, and storage	**Predominant scenarios adopted from the TSO/DSO for anticipated penetrations**
Expected update rate	-
Coverage	For a period of 1 to 10 years

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Resolution	Single values
Weather forecasts	**Forecasted time series of weather-related data**
Expected update rate	Hourly
Coverage	Minimum period of 1 year
Resolution	Hourly
Historical planned and unplanned outage events / reliability data	**List of historical planned and unplanned events (equipment/network failures, reliability data)**
Expected update rate	Monthly
Coverage	Minimum period of 5 years
Resolution	List of events
Metering data	**Time series of historical smart meter data from the DSO at the relevant areas**
Expected update rate	Daily
Coverage	Minimum period of 1 year
Resolution	Hourly
Assets' characteristics, network topology	**Power rate specifications, capacity levels of assets (substations/lines, cables), buses connections**
Expected update rate	-
Coverage	-

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Resolution	-

Along with the definition of input data, the list of algorithmic processes executed in the component, or analytics executed in the platform and required by the component are defined.

Firstly, raw meter data is and historical time series are processed , along with forecast time series to generate sample demand and generation scenarios. Afterwards, power flows are executed to identify critical components and conditions.

Table 11: Network performance assessment engine algorithms

Generate sample demand scenarios for characteristic weeks of the year	**Provide probabilistic time series demand data**
Required inputs	Historical demand time series, medium and long-term forecasts of demand Anticipated peaks, probability distributions
Expected outputs	Probabilistic demand
Generate sample generation scenarios for characteristic weeks of the year	**Provide probabilistic time series generation data**
Required inputs	Historical generation time series, medium and long-term forecasts of generation Anticipated penetrations, probability distributions
Expected outputs	Probabilistic generation
Execute power flows for specific instances,	**Perform power flow calculations**

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for time series and different scenarios	
Required inputs	Network topology, network parameters
Expected outputs	Power flows
Detect congestion problems	**Investigation and detection of network constraints violations**
Required inputs	Power flow results, network characteristics
Expected outputs	Congestion detection
Statistically analyse power flow results	**To provide probability, frequency, range and duration of congestion occurrence**
Required inputs	Probabilistic power flow results
Expected outputs	Frequency, range and duration of congestions and critical operational events
Calculate status indicators	**To indicate flexibility and reinforcement needs and critical network components**
Required inputs	power flow results
Expected outputs	Status indicators for the period under study (short term or long term)

Moreover, a list of inputs required for the execution of algorithms can be delivered to the application as results of analytics of other apps running in SYNERGY platform. These are summarized in the following table.

Table 12: Network performance assessment engine- analytics provided by the SYNERGY platform

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 872734.

Forecast of long term DER generation	**Long term (over a year) energy generation at the relevant TSO /DSO areas (substation and feeder level)**
Expected update rate	Daily
Coverage	Minimum period of 1 year
Resolution	hourly
Forecast of long-term demand	**Long term (over a year) monthly demand forecast**
Expected update rate	Monthly
Coverage	Minimum period of 1 year
Resolution	hourly
Forecast of long-term demand	**Long term (over a year) monthly demand forecast, peak and average values**
Expected update rate	Monthly
Coverage	Minimum period of 1 year
Resolution	hourly

Details about the outcomes of the algorithms and presented to end users in the UI of the Network Performance Assessment Engine are presented in the following table:

Table 13: Network performance assessment outcomes

Probabilistic demand and generation scenarios	**Hourly profiles for representative days, including boxplots and probability distributions**
Expected update rate	-

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Coverage	-
Resolution	hourly
Power flow results	**Active and reactive power flow results for the tested demand and generation scenarios**
Expected update rate	-
Coverage	-
Resolution	hourly
Detected congestions	**Identification and statistical representation of equipment over loadings**
Expected update rate	-
Coverage	-
Resolution	-

3.1.1.2 Network Assets Sizing Engine

The Network Assets Sizing Engine (NASE) is responsible for providing solutions regarding optimal planning and sizing of the network assets. Solutions shall involve optimal capacity for new substations and lines in case further reinforcements are needed, as well as optimal sizing of new demand connections or DERs.

The Network Assets Sizing Engine is a complementary component to the Network Performance Assessment Engine, exploiting results such as reinforcement and flexibility needs to propose operational planning solutions in the mid-term (up to a month ahead) and in the long term (up to a year) for the provision of critical services such as congestion management in medium voltage distribution grids.

As depicted in the component diagram, additional input data consists on the historical meter data of the network operator, anticipated penetrations , exogenous variables, such as weather forecasts and outputs from other SYNERGY applications such as short and long term forecasts.

After processing the aforementioned data, mid term flexibility planning and long term expansion planning algorithms are executed and final planning decisions and and planning indicators are displayed through the UI of the application.

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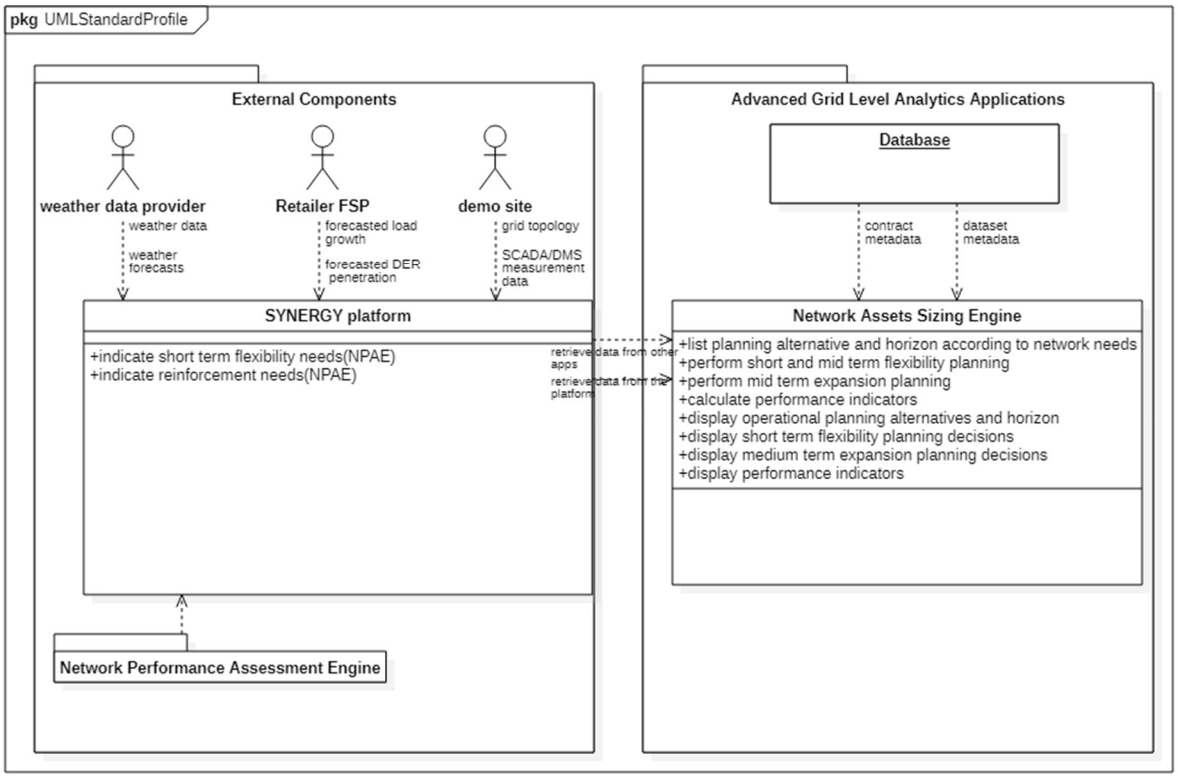

Figure 7: Network Assets Sizing Engine Component Diagram

More details on the features, data inputs/outputs and algorithms to be performed by the component are provided hereby. The list of features offered by the Network Assets Sizing Engine, as initially have been described in D2.6, includes:

Table 14: Features delivered within Network Assets Sizing Engine

Feature	Description
NASE_1	**List operational planning alternatives and horizon**: Chronological probabilistic pf simulation shall help identify probability of congestion, range of congestion and frequency of occurrence of congestion and therefore understanding on whether the grid issue is long standing, short term, episodic (happening in a rare occurrence) or periodic. The Network Assets Sizing Engine shall give insights on whether the proposed planning solution shall be a short term (for specific hours or weeks of the forthcoming period) flexibility-based approach or alternatively a more long-term solution involving grid reinforcements.

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NASE_2	**Mid – term flexibility planning**: The Network Assets Sizing Engine allows the use of DERs and other flexible demand to be utilized for a range of grid services, including capacity and voltage control services with the aim to keep the network operation safe and secure. These flexible technologies shall be incorporated in the power flow analysis where load dynamics can be emulated, preferably in a chronological simulation to properly identify and solve congestions and capacity violations.
NASE_3	**Long term expansion planning**: The Network Assets Sizing Engine shall facilitate proper capacity sizing for substations, lines as well as new demand connections or DERs to ensure an optimum expansion which satisfies N-1 security criteria and voltage drop constraints, and minimizes technical losses at the primary network level. Load distribution especially during peak demand periods, forecasted load growth, anticipated penetration of EVs, storage and RES technologies and additional flexibility capacity means enabled by demand side response are also considered. Additionally, capital costs and depreciation rate of grid assets shall also be considered to allow the selection of appropriate conductor's cross section areas to guarantee normal operation and back up capacity needed.
NASE_4	**KPIs calculator – performance indicators**: The performance indicators of the Network Assets Sizing Engine give an overview on the performance of network operation under the different planning alternatives and other metrics related to planning decisions. Relevant KPIs include cost savings, identification of DER hosting capacity.
NASE_5	**Data ingestion:** Allow and build interaction with the SYNERGY platform to access any data, measurements, grid models stored in the platform.

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The list of input data of the Network Assets Sizing Engine is presented in the following table.

Table 15: Network Asset Sizing Engine data inputs

Anticipated load growth	**Anticipated load growth for the forthcoming period of analysis**
Expected update rate	Yearly
Coverage	For the next 1 to 10 years
Resolution	Single values
Anticipated DER penetration	**Anticipated DER penetration for the forthcoming period of analysis**
Expected update rate	Yearly
Coverage	For the next 1 to 10 years
Resolution	Single values
Network Planning Parameters	**Annual load factor, coincidence factor, cost of losses, investment costs, reliability costs**
Expected update rate	Yearly
Coverage	For the next 1 to 10 years
Resolution	Single values

Along with the definition of input data, the list of algorithmic processes executed in the component, or analytics executed in the platform and required by the component are defined.

Firstly, identified flexibility needs and reiforcement needs from the NPAE are utilized by this component, to indicate planning decision for the next months to year. Moreover, optimal assets sizing for DER and expansion for the network components is calculated.

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Table 16: Network Assets Sizing Engine algorithms

Short and mid-term flexibility planning	**Execute planning for the next weeks to months utilizing flexible demand and DER**
Required inputs	Flexibility costs
Expected outputs	Indicate short term planning decisions
Long term expansion planning	**Execute planning for the next year including upgrade of components and sizing of DER**
Required inputs	Reinforcement costs
Expected outputs	Indicate long term planning decisions
Calculate performance indicators	**Measure impact of planning decisions**
Required inputs	Power flow results
Expected outputs	Performance indicators for the period under study (short term or long term)

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Moreover, a list of inputs required for the execution of algorithms can be delivered to the application as results of analytics of other apps running in SYNERGY platform. These are summarized in the following table.

Table 17: Network Assets Sizing Engine- analytics provided by the SYNERGY platform

Forecast of long-term DER generation	**Long-term (over a year) energy generation at the relevant TSO /DSO areas (substation and feeder level)**
Expected update rate	Daily
Coverage	Minimum period of 1 year
Resolution	hourly
Forecast of long-term demand	**Long-term (over a year) monthly demand forecast**
Expected update rate	Monthly
Coverage	Minimum period of 1 year
Resolution	hourly
Network status indicators (flexibility and reinforcement needs)	**Indicative flexibility and reinforcement needs as calculated within the network performance assessment engine**
Expected update rate	-
Coverage	Test period
Resolution	Single values

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Details about the outcomes of the algorithms and presented to end users in the UI of the Network Assets Sizing Engine are presented in the following table:

Table 18: Network Assets Sizing Engine outcomes

Short term planning decision indicators	**Indicative capacity requirements from flexible demand and other financial planning indicators for the horizon studied**
Expected update rate	-
Coverage	-
Resolution	Single values
Long term planning decisions indicators	**Indicative capacity requirements from DER, grid reinforcement decisions and other financial planning indicators for the horizon studied**
Expected update rate	-
Coverage	-
Resolution	Single values

3.1.2 User stories

The user interface will be provided in the form of a web application. The network operators will have access to a number of visualizations related to the analysis performed by this application.

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The first step would be to examine the network topology, by navigating through the network components and then getting an overview of their parameters. Additionally, the single network diagram of the network under study can be also retrieved.

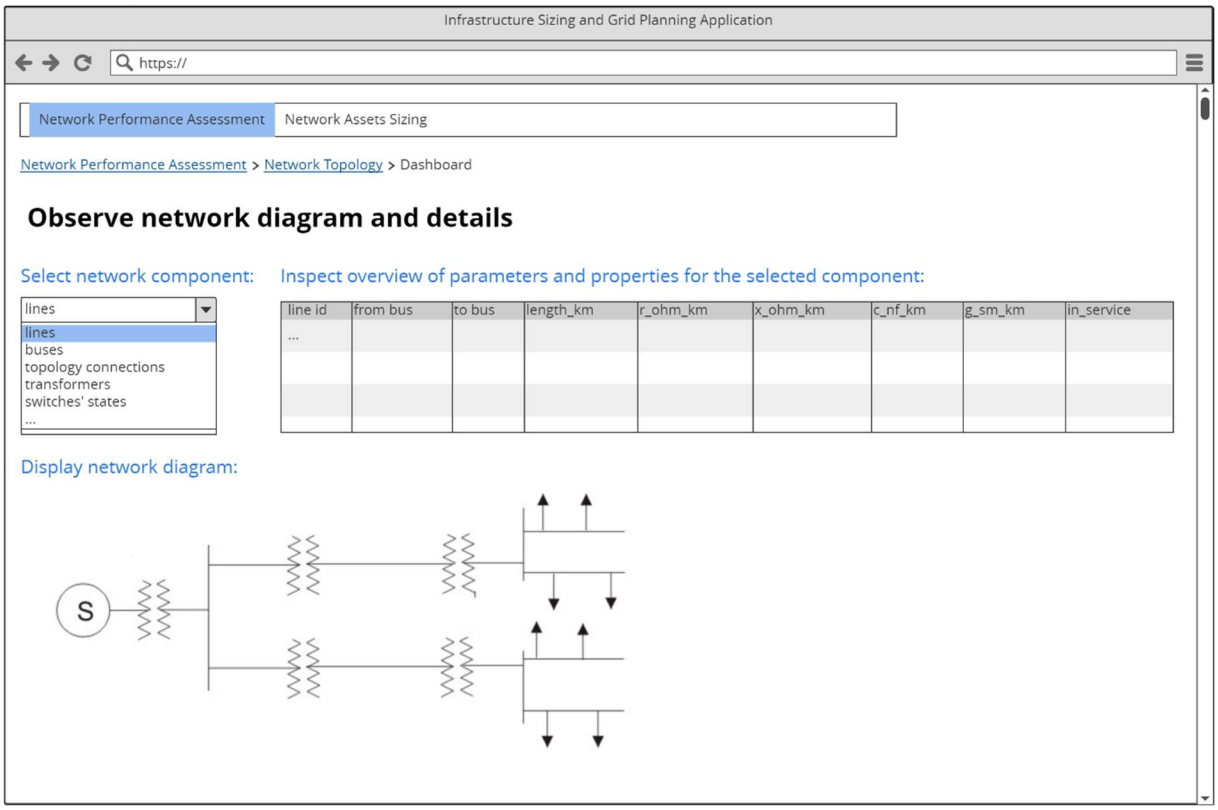

Figure 8: NPAE -network topology mock up

Next, the user shall select the anticipated percentage penetrations of DERs and load growth, which are used as an input parameter for the generation of probabilistic scenarios.

The subsequent step is to display the generated probabilistic scenarios for demand and generation. The user can select the category of the representative day, picking the season of preference and the type of day (weekday or weekend). For the selected day type, one can see variations of demand/generation through boxplots, displaying seasonal variations and also through time series profiles, for the 24 hours of day, allowing the generation of test profiles which lay between upper and lower bounds, and their associated average hourly seasonal profiles.

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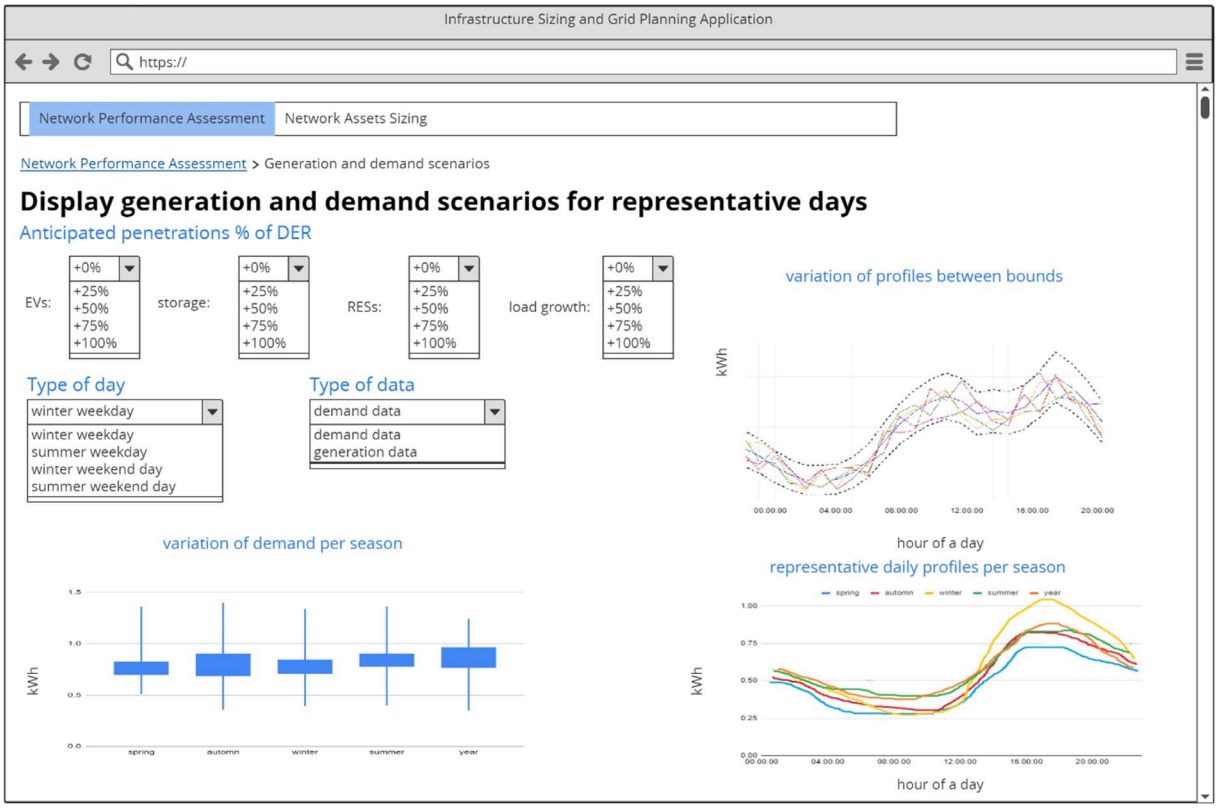

Figure 9: NPAE- demand and generation tested scenarios

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For the generated tests of demand and generation scenarios, the user is able to have an overview of the power flow results, and more specifically on the loading conditions of the network's components, i.e. buses and lines. The loading condition is presented in percentage form, which is calculated as the ratio of the current equipment loading to the nominal capacity of the equipment. These graphs would provide the user with a first insight of the size and the frequency of possible over-loadings.

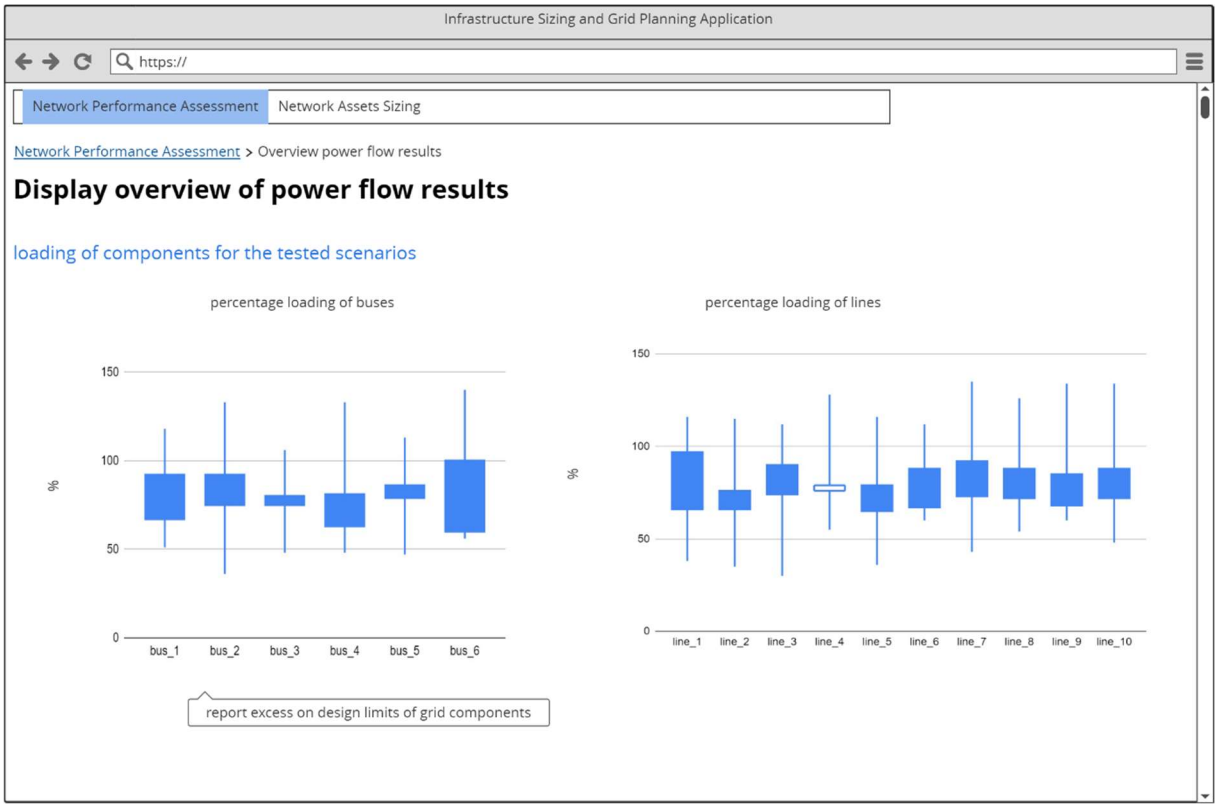

Figure 10: NPAE- overview of power flow results

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Apart from the overview results, the user can select to display hourly power flow results of one representative day. Indicative outputs can be the injected active power and the injected reactive power at the network's buses. Alternatively, the user could select to display results of a specific snapshot of interest, such as a selected combination of load and generation or peak values.

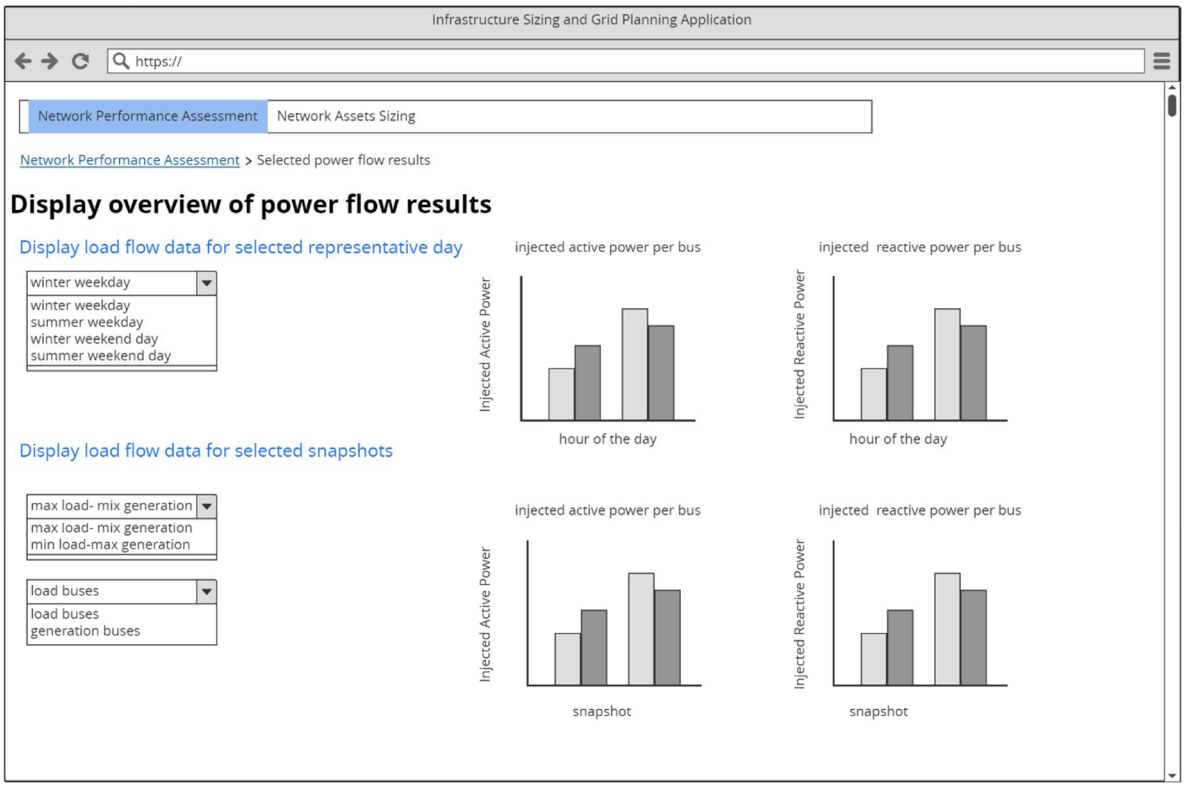

Figure 11: NPAE- display overview of selected power flow results

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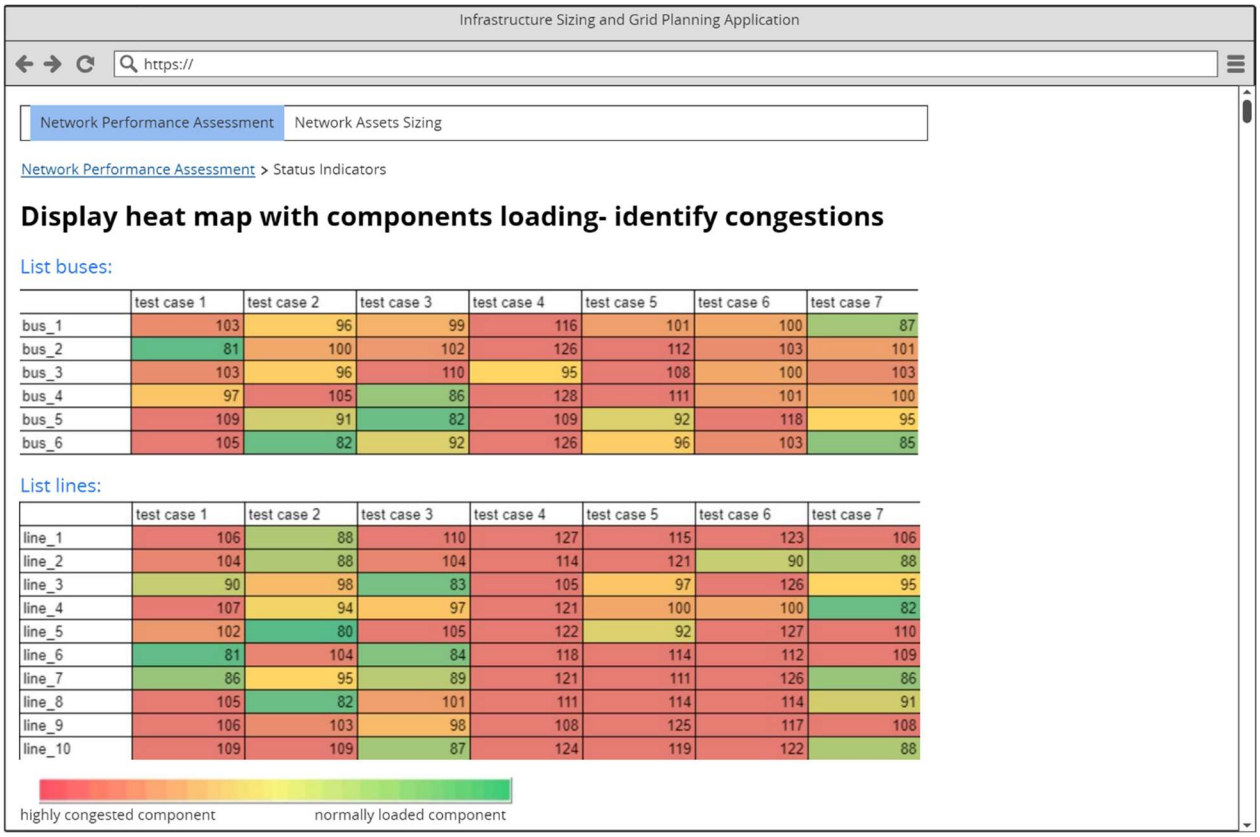
The user can navigate to a set of status indicators, which encapsulate the status of the network under the examined scenarios. Critical lines and buses can be identified through a heat map, where red color indicates the components with high contingency probability.



	test case 1	test case 2	test case 3	test case 4	test case 5	test case 6	test case 7
bus_1	103	96	99	116	101	100	87
bus_2	81	100	102	126	112	103	101
bus_3	103	96	110	95	108	100	103
bus_4	97	105	86	128	111	101	100
bus_5	109	91	82	109	92	118	95
bus_6	105	82	92	126	96	103	85

	test case 1	test case 2	test case 3	test case 4	test case 5	test case 6	test case 7
line_1	106	88	110	127	115	123	106
line_2	104	88	104	114	121	90	88
line_3	90	98	83	105	97	126	95
line_4	107	94	97	121	100	100	82
line_5	102	80	105	122	92	127	110
line_6	81	104	84	118	114	112	109
line_7	86	95	89	121	111	126	86
line_8	105	82	101	111	114	114	91
line_9	106	103	98	108	125	117	108
line_10	109	109	87	124	119	122	88

Figure 12: NPAE- display overview with components loading

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Another set of status-indicators, providing information for the criticality of congestions, can be available for the user. Histograms which show the expected frequency and size of the congestions for the number of examined test cases. Those can be displayed on aggregated values at the substation level selected by the user.

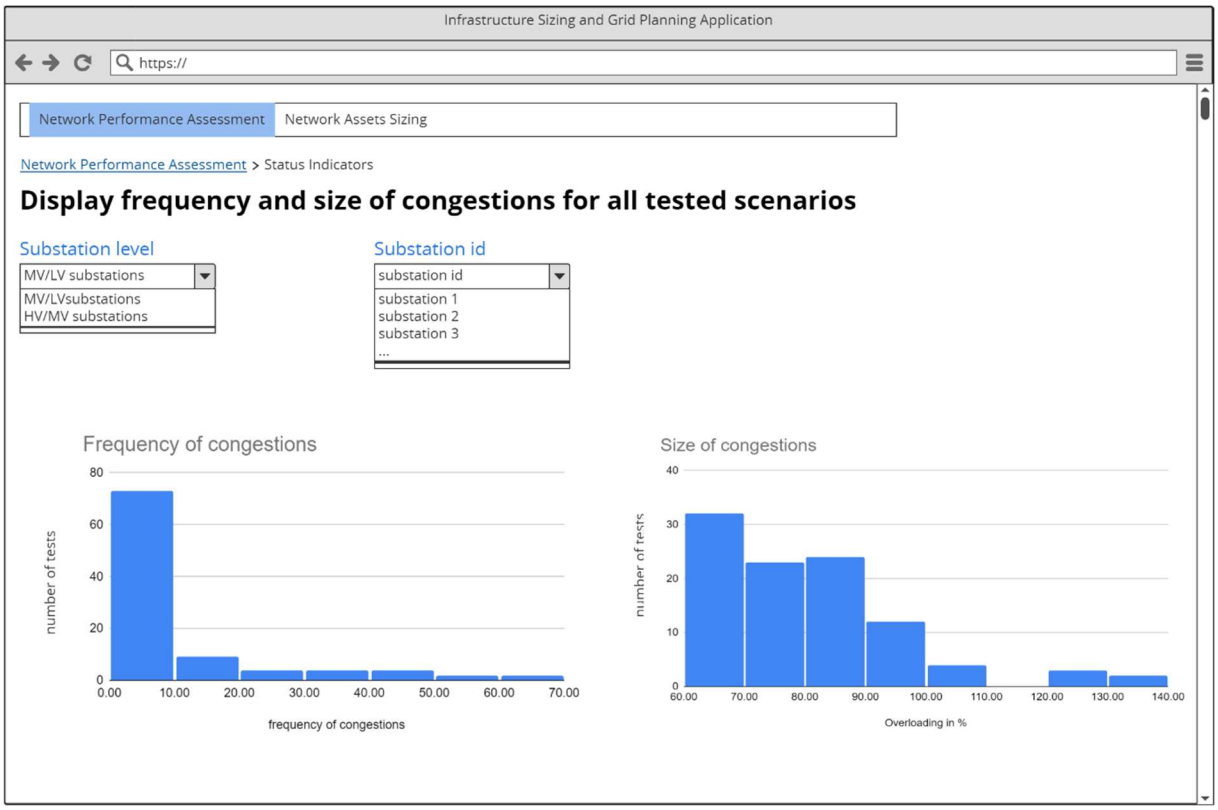

Figure 13: NPAE- display histograms of congestions

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The last graphs related to the status indicators of Network Performance Assessment display the amount of flexibility needs in MWs per substation and in aggregated mode for the selected time horizon. Apart from flexibility needs, capacity reinforcement needs can also be displayed for the user, for the selected lines and transformers and are also indicated in MW for the selected horizon.

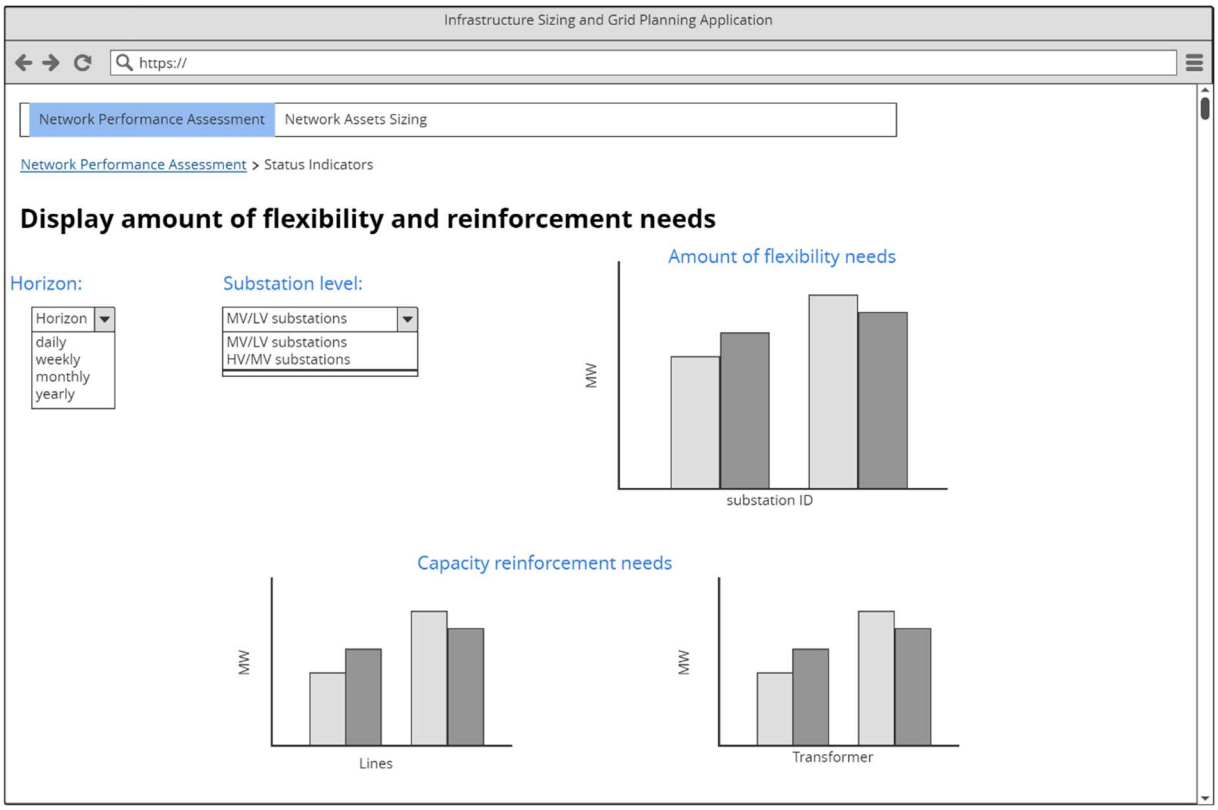

Figure 14: Display amount of flexibility and reinforcement needs

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During the first step at the Network Asset Sizing site, the user shall proceed to the planning preparation, including the selection of the operational planning horizon and the operational planning alternatives that should be considered in the analysis, for example whether they want to utilize only flexible demand and DER for a mid-term solution, or they also want to consider equipment upgrades for a more long-term solution.

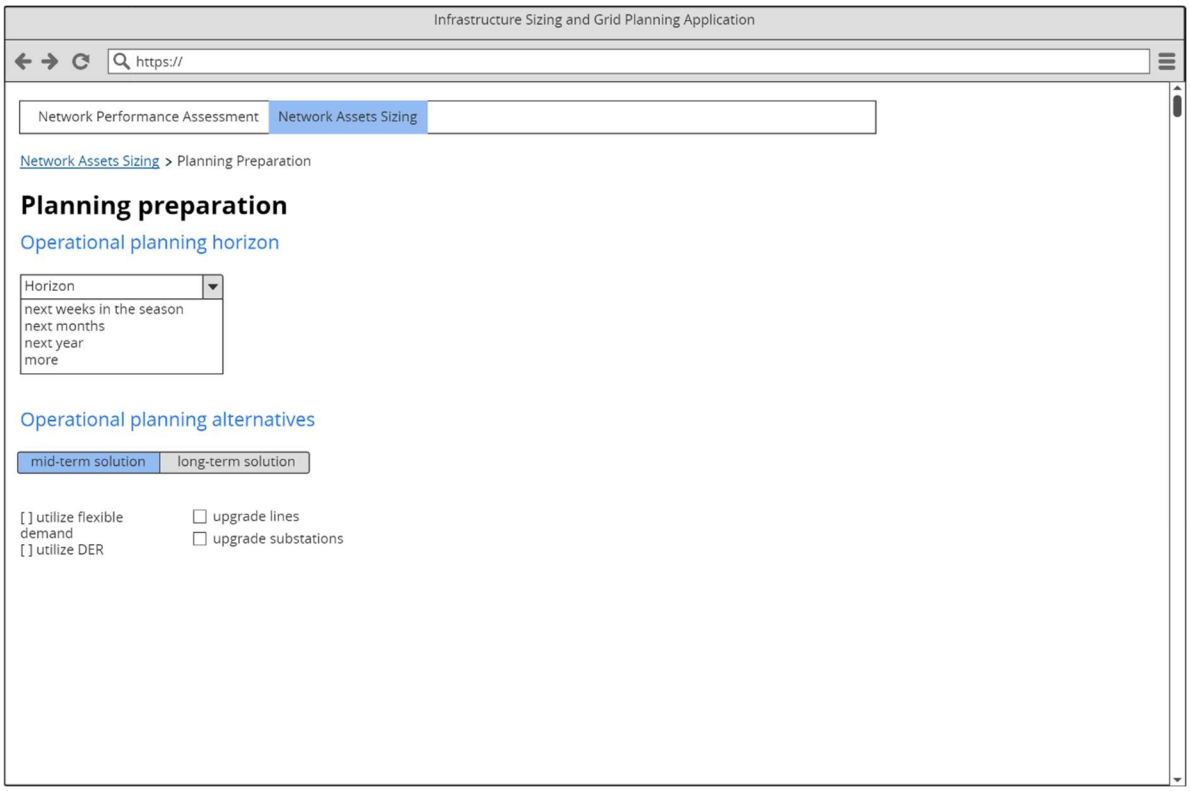

Figure 15: NASE – planning preparation mock up

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After the planning preparation phase, the user can navigate through the planning results, selecting the horizon of interest and viewing a list of relevant indicators categorized in flexibility-based planning indicators and expansion planning indicators. Flexibility-based planning indicators may include active power deviation from flexible units, congestion alleviation, financial benefits for the operator and number of flexibility activations requested by the operator. Expansion planning indicators may include average time of fault mitigation, flexible capacity, cost savings for the operator and DER hosting capacity.

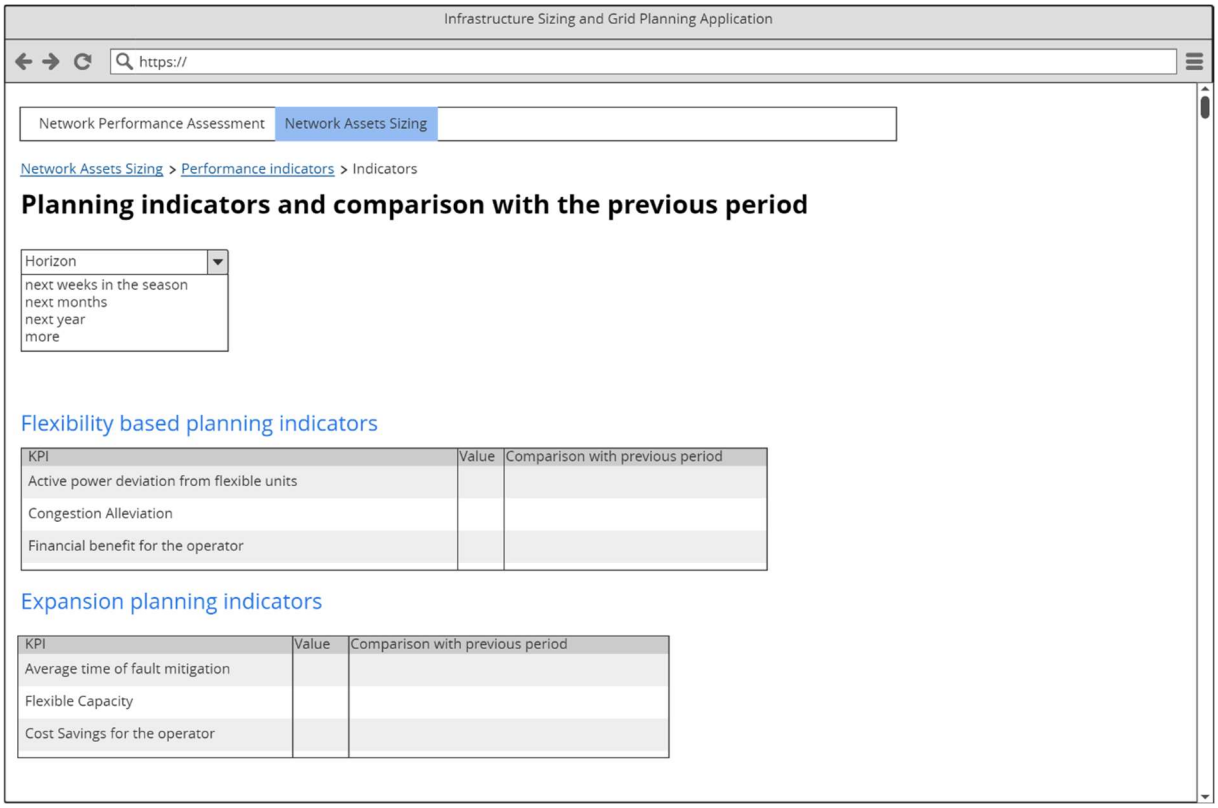

Figure 16: NASE- planning indicators mock up

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3.1.3 Exploited technology stack

In order to meet the requirements of the platform, the Infrastructure Sizing and Grid Planning Application will be developed on state-of-the art technologies, namely: (a) in the back-end & the front-end layer, Django Web framework of Python for serving the components as an efficient, secure and scalable REST API, (b) in the data storage layer, SQL Server as the relational database for local power grid calculations, (c) in the application layer, Python programming language and its related libraries (pandapower, pygurobi, etc.) for fast and accurate power grid calculations

3.2 Flexibility based network management and DSO-TSO Common Operational Scheduling

The Flexibility based Network Management and DSO-TSO common operational scheduling Application implements all necessary features to allow network operators to operate their networks and schedule the available resources including flexible demand for the intra-day and day ahead in a coordinated manner. By exploiting all available data, including the flexibility potential of aggregators' portfolio, the application facilitates the optimal scheduling of the flexible assets by TSOs and DSOs who aim to request specific congestion management and balancing services.

The application consists of two main operational components, the Flexibility based Network Manager, which includes data exchange with other SYNERGY apps to inform the network operators regarding flexibility availability estimates from aggregators, and the DSO-TSO Common Operational Scheduler, which facilitates operational scheduling of the network operators under an adopted coordination scheme. The coordination between the two operators is based on the 'local ancillary services market' scheme which has been proposed in the literature [37] [38], where a local market operated by the DSO is introduced and the DSO actively participates in the Ancillary Services market clearing. Priorities are shifted towards the DSO, which means that the DSO has the priority over flexibility located at the distribution network. The TSO can only contract DER indirectly, after the DSO has aggregated these resources and has transferred them to the TSO AS market. The concept and the sequence of actions among the actors involved is summarized in Figure 18.

Apart from the main operational components, there are also the supporting software components, that have been presented in 3.1 and facilitate data ingestion and interaction with other SYNERGY energy applications and generally the overall SYNERGY platform.

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The details of the different operational components that consist of the Flexibility based Network Management and DSO-TSO common operational scheduling Application are presented in the following subsections.

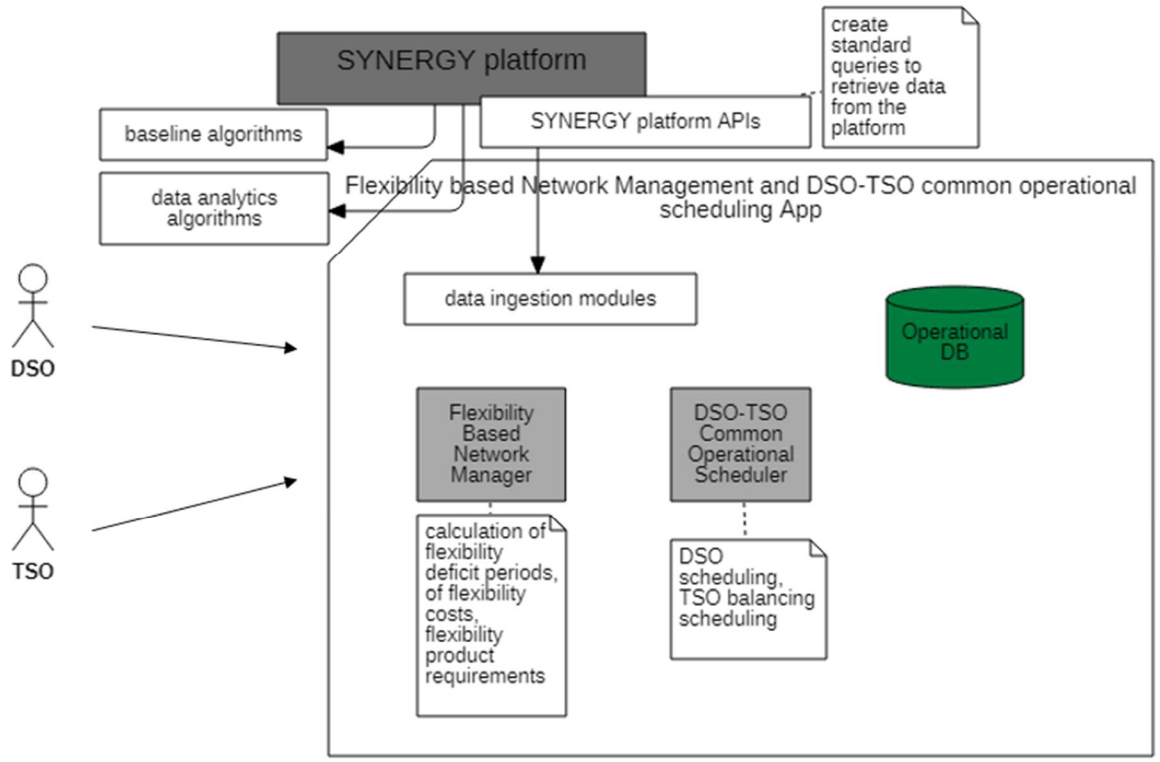

Figure 17: Flexibility based Network Management and DSO-TSO common operational scheduling Application

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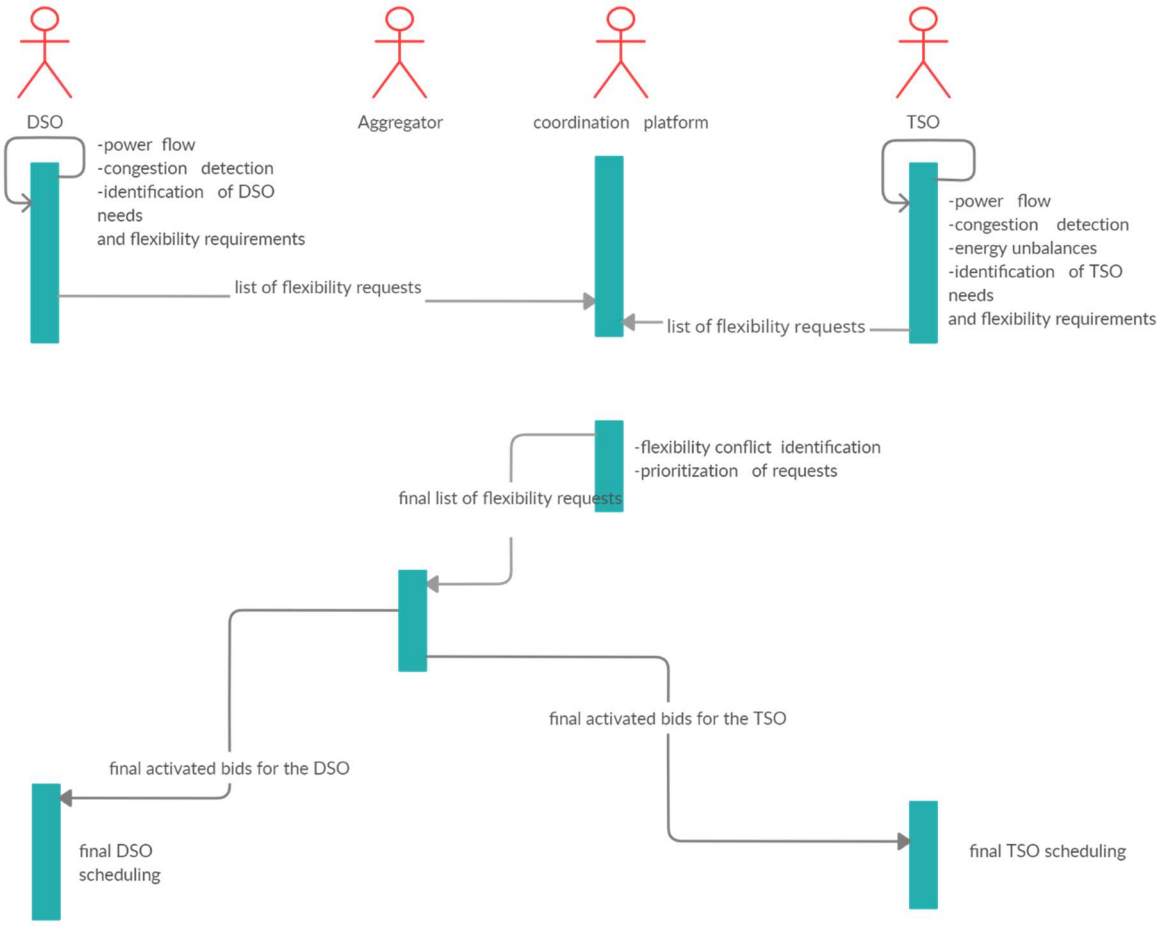

Figure 18: Sequence of actions and interactions diagram among actors on the adopted DSO-TSO coordination scheme 'local AS market'

3.2.1 Component details

3.2.1.1 Flexibility based Network Manager

The Flexibility Based Network Manager (FBNM) is responsible for assisting network operators to perform their short-term planning activities by utilizing available flexibility. The manager involves the process of data exchange regarding flexibility availability between flexibility providers and network operators, identification of aggregated flexibility in substation and feeders' level, identification of flexibility deficit periods and calculation of flexibility margins and requirements for network operators to facilitate their short-term planning. The FBNM shall utilize short- term (for the next 1 to 72 hours) flexibility estimations received by the aggregator portfolio management engines, and short-term

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demand and generation forecasts received from the portfolio pattern forecasting engine, for the MV/LV feeders and substation under consideration. The component shall define flexibility products expressing TSO and DSO requirements and needs for congestion management and balancing, as well as flexibility deficit periods. The above are also depicted in the component diagram below.

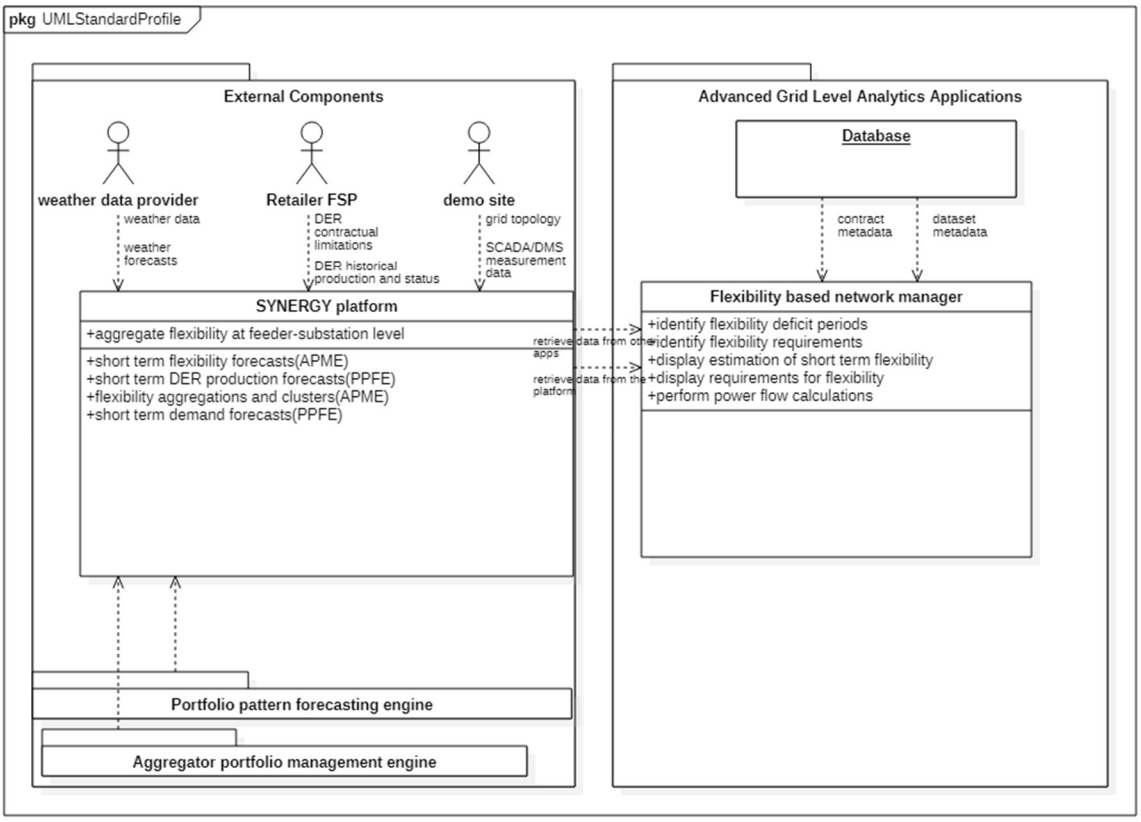

Figure 19: Flexibility based Network Manager Component Diagram

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More details on the features, data inputs/outputs and analytics to be performed by the component are provided hereby. The list of features offered by the Flexibility based Network Manager, as initially have been described in D2.6, includes:

Table 19: Features offered by the Flexibility Based Network Manager

Feature	Description
FBNM_1	**Data exchange between flexibility service providers and network operators:** FBNM_1 will share the required inputs (flexibility availability, DER production, DR flexibility) to identify available flexibility on substation and feeder level. The aggregated DER available flexibility shall be available to network operators at feeder and substation level to help them plan their control actions in case of system needs. Time resolution of available flexibility data shall be in 15, 30- or 60-minutes intervals. Time horizons of calculated available aggregated flexibility shall be from 1 to 72 hours. The resulting estimated flexibility profiles shall contain information and insights for the flexibility characteristics such as flexibility deficit periods, seasonal characteristics, temperature sensitivities and other parameters to characterize flexibility.
FBNM_2	**Identification of requirements for flexibility:** Identify operational issues on the TSO and DSO level, balancing and congestion management needs and flexibility requirements. Requirements will be calculated for the short-term horizon and can be also translated as flexibility requests. This can contain a list of parameters which identify an individual service, for example delivery period or delivered load change, service duration.

The list of input data of the Flexibility based Network Manager is presented in the following table.

Table 20: Flexibility based Network Manager data inputs

Weather forecasts	**Forecast time series of weather-related data**
Expected update rate	Hourly

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Coverage	Minimum period of 1-72 hours
Resolution	15 minutes
Assets' characteristics, network topology	**Power rate specifications, capacity levels of assets (substations/lines, cables), buses connections**
Expected update rate	-
Coverage	All assets
Resolution	-

The following table presents the algorithms executed in the Flexibility Based Network Manager.

Table 21: Flexibility based Network Manager algorithms

Aggregate flexibility estimates received from portfolio analytics engine	**Aggregate at substation level the flexibility estimates received from the SYNERGY platform**
Required inputs	Time series of flexibility estimation
Expected outputs	Aggregation of flexibility in substation and feeder level
Identification of margins/ and requirements for flexibility	**To run network operational studies to extract network margins and flexibility requirements**
Required inputs	Network capacity limits Flexibility resources limitations
Expected outputs	Margins to increase/decrease load in each feeder

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Calculate flexibility deficit periods	**To identify deficits on flexibility requirements during the scheduling period**
Required inputs	Resulting Flexibility scheduling Timeseries of estimated flexibility
Expected outputs	Time series of flexibility deficit
Identify flexibility products in need	**To identify flexibility requirements of network operators and describe them in terms of services**
Required inputs	Knowledge of market set up
Expected outputs	Correspond flexibility requirements to available market products

Moreover, a list of inputs required for the execution of algorithms can be delivered to the application as results of analytics of other apps running in SYNERGY platform. These are summarized in the following table.

Table 22: Flexibility based Network Manager- datasets provided by the SYNERGY platform

Forecast of short term DER generation	**1-72 hours ahead of energy generation at the relevant TSO /DSO areas (substation and feeder level)**
Expected update rate	Hourly
Coverage	Minimum period of 1-72 hours
Resolution	15 minutes
Forecast of short-term demand	**1-72 hours ahead of energy demand at the relevant TSO /DSO areas (substation and feeder level)**
Expected update rate	Hourly

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Coverage	Minimum period of 1-72 hours
Resolution	15 minutes
Forecast of short-term flexibility	**1-72 hours ahead of flexible demand at the relevant TSO /DSO areas (substation and feeder level)**
Expected update rate	Hourly
Coverage	Minimum period of 1-72 hours
Resolution	15 minutes
Flexibility potential	**Time series of flexibility potential per each DER of the portfolio**
Expected update rate	Hourly
Coverage	Minimum period of 1-72 hours
Resolution	15 minutes
Aggregations of flexibility potential	**Aggregate flexibility values per aggregator portfolio**
Expected update rate	Daily
Coverage	Minimum period of 1-72 hours
Resolution	15 minutes

Details about the outcomes of the algorithms and presented to end users in the UI of the Flexibility based Network Manager are presented in the following table:

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Table 23: Flexibility based Network Manager outcomes

Aggregation of flexibility in substation and feeder level	***Aggregated flexibility potential time series per substation***
Expected update rate	Hourly
Coverage	Substation level
Resolution	15 minutes
Margins and requirements to increase/decrease load in each feeder/substation	**For each feeder/substation margins to increase/decrease load**
Expected update rate	Daily
Coverage	Asset type
Resolution	-
Time series of flexibility deficit	**Time series of flexibility deficit per substation**
Expected update rate	Daily
Coverage	Substation level
Resolution	15 minutes

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3.2.1.2 DSO-TSO Common Operational Scheduler

The DSO-TSO Common Operational Scheduler is responsible for providing a common interface for the DSO and the TSO to facilitate common operational scheduling, considering the flexibility requirements for both actors for congestion management needs, balancing needs and other relevant ancillary services. The scheduler also is there to clarify the sequence of actions and information exchange between the two operators, propose an appropriate coordination scheme, identify the definite short term operational scheduling for both actors. Relevant inputs from external sources, inputs received as outcomes from other apps of SYNERGY, and processes and algorithms executed within the application are summarized in the component diagram below.

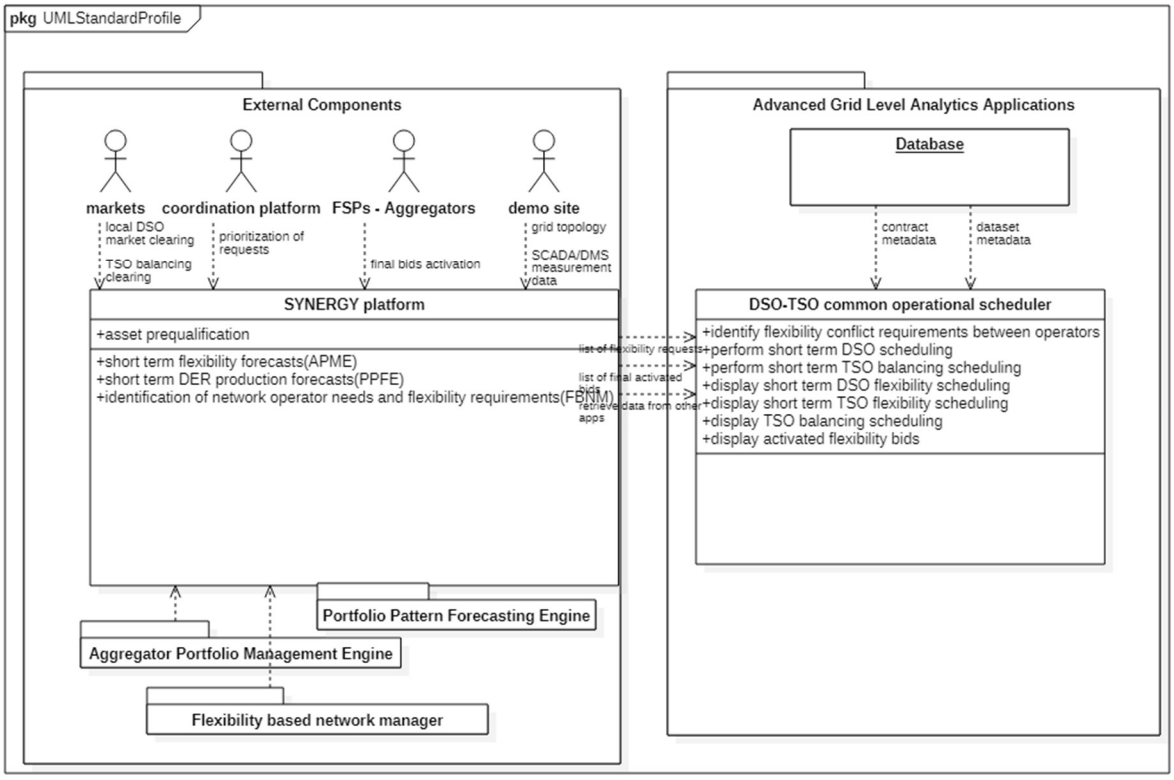

Figure 20: DSO-TSO Common Operational Scheduler Component Diagram

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More details on the features, data inputs/outputs and analytics to be performed by the component are provided hereby. The list of features offered by the DSO-TSO Common Operational Scheduler, as initially have been described in D2.6, includes:

Table 24: Features contained in the DSO-TSO Common Operational Scheduler

Feature	Description
DSO-TSO_1	**DSO-TSO coordination scheme:** The DSO-TSO Common Operational Scheduler also describes the pre-agreed coordination scheme between the DSO and the TSO regarding daily system operational activities, pre-agreed processes with respect to market design and system security, regarding procurement of ancillary services for balancing and congestion management from resources located in the distribution grid. The proposed scheme shall be a decentralized or a centralized one, where the system control responsibilities are specifically allocated among the actors involved, considering day ahead market clearing, real time market clearing, forecast errors and network constraints, participation of DER to the flexibility market with predefined rules and priorities between TSO and DSO needs. Data exchange procedures between TSOs and DSOs are also described.
DSO-TSO_2	**Flexibility Conflict Identifier:** Network performance assessment in transmission and distribution networks shall indicate flexibility requirements for both networks to confront congestion issues and other power imbalances. Pre-agreed priorities to access flexibility resources, depending also on where these resources are located (for example DERs located in the distribution grid), and depending also on the adapted coordination scheme, would indicate any arising conflicts on the flexibility requirements of the DSO and the TSO. In addition, the flexibility conflict identifier along with a certain grid prequalification process, shall ensure that the activation of any flexibility services at a certain point would not cause operational issues and other undesirable situations in either of the involved grids.
DSO-TSO_3	**Short-term operational scheduling:** The DSO-TSO Common Operational Scheduler allows the coordinated TSO-DSO optimal power flow calculations

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	which indicate the resulting short-term operational scheduling for the DSO and the TSO, acquiring flexibility products for congestion mitigation, even for different time horizons, as for instance scheduling flexibility for DSO congestion at specific hours during the day and then scheduling part of remaining available flexibility to deal with real time TSO imbalances, while respecting DSO network constraints. DSO-TSO coordinated scheduling assumes constant DSO-TSO interactions, performance tests in both networks involved to reassure that network technical requirements are met.

The list of input data of the DSO-TSO Common Operational Scheduler is presented in the following table.

Table 25: DSO-TSO Common Operational Scheduler data inputs

Weather forecasts	**Future time series of weather-related data**
Expected update rate	Hourly
Coverage	Minimum period of 24 hours
Resolution	15 minutes
Assets' characteristics, network topology	**Power rate specifications, capacity levels of assets (substations/lines, cables), buses connections**
Expected update rate	-
Coverage	All assets
Resolution	-
Local DSO market clearing	**DSO submits bids for flexibility requests to cover congestion management requirements, flexibility service providers submit their**

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	offers, the market is cleared and a list of the final activated bids is provided
Expected update rate	Hourly
Coverage	Minimum period of 24 hours
Resolution	15 minutes
TSO balancing market clearing	**TSO submits bids for flexibility requests to cover balancing requirements, flexibility service providers submit their offers, the market is cleared and a list of the final activated bids is provided**
Expected update rate	Hourly
Coverage	Minimum period of 24 hours
Resolution	15 minutes
TSO market clearing	**TSO submits bids for flexibility requests to cover congestion management requirements, flexibility service providers submit their offers, the market is cleared and a list of the final activated bids is provided**
Expected update rate	Hourly
Coverage	Minimum period of 24 hours
Resolution	15 minutes

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The following table presents the algorithms executed in the DSO-TSO Common Operational Scheduler.

Table 26: DSO-TSO Common Operational Scheduler

Identify conflicts in flexibility requirements between operators	**Compare flexibility requirements time series from the DSO and the TSO and identify conflicts in flexibility needs**
Required inputs	List of flexibility requests (containing time frame, location, capacity/energy requirements)
Expected outputs	List of conflicts between requests
Short term DSO scheduling	**DSO performs optimal scheduling algorithms to decide scheduling for the next hours**
Required inputs	Forecasts of short-term demand, Forecasts of short term DER/RES generation
Expected outputs	Upward and downward flexibility scheduling Power deviation short term scheduling
Short term TSO scheduling	**TSO performs optimal scheduling algorithms to decide scheduling for the next hours and bid for flexibility**
Required inputs	Forecasts of short-term demand, Forecasts of short term DER/RES generation
Expected outputs	Upward and downward flexibility scheduling Power deviation Day ahead/intraday/balancing scheduling

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Prioritization of requests	**Flexibility requests from DSO and TSO are prioritized according to the agreed coordination scheme**
Required inputs	Coordination agreement and rules
Expected outputs	Priority list of flexibility requests

Moreover, a list of inputs required for the execution of algorithms can be delivered to the application as results of analytics of other apps running in SYNERGY platform. These are summarized in the following table.

Table 27: DSO-TSO Common Operational Scheduler- datasets provided by the SYNERGY platform

Forecast of short-term DER generation	**1-72 hours ahead of energy generation at the relevant TSO /DSO areas (substation and feeder level)**
Expected update rate	Hourly
Coverage	Minimum period of 1-72 hours
Resolution	15 minutes
Forecast of short-term flexibility	**1-72 hours ahead of flexible demand at the relevant TSO /DSO areas (substation and feeder level)**
Expected update rate	Hourly
Coverage	Minimum period of 1-72 hours
Resolution	15 minutes
Forecast of short-term demand	**1-72 hours ahead of energy demand at the relevant TSO /DSO areas (substation and feeder level)**
Expected update rate	Hourly

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Coverage	Minimum period of 1-72 hours
Resolution	15 minutes
Flexibility margins	**Margins to increase/decrease load at network buses**
Expected update rate	Daily
Coverage	Minimum period of 1-72 hours
Resolution	Hourly

Details about the outcomes of the algorithms and presented to end users in the UI of the DSO-TSO Common Operational Scheduler are presented in the following table:

Table 28: DSO-TSO Common Operational Scheduler outcomes

List of conflicts between requests	**List of conflicting requests for flexibility activation from DSO and TSO**
Expected update rate	Hourly
Coverage	TSO/DSO area under scheduling
Resolution	Type of issue/alert
Short term flexibility scheduling	**Short term flexibility scheduling from the network operator targeting day ahead or intra-day markets**
Expected update rate	Hourly
Coverage	TSO/DSO area under scheduling
Resolution	15 minutes
Priority list of flexibility requests	**List of priorities between flexibility requests according to the coordination scheme**

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Expected update rate	Hourly
Coverage	TSO/DSO area under scheduling
Resolution	Type of issue/alert

3.2.2 User stories

The user interface will be provided in the form of a web application. The network operators will have access to a number of visualizations related to the analysis performed by this component.

The user is prompted to select the dates of interest, in the short-term period to follow, in order to navigate through short term power flow results. Relevant results might be flexibility capacity requirements in substation level and flexibility deficit profile for the number of selected hours ahead. The user can select the number of hours they want to look ahead with starting time the current time.

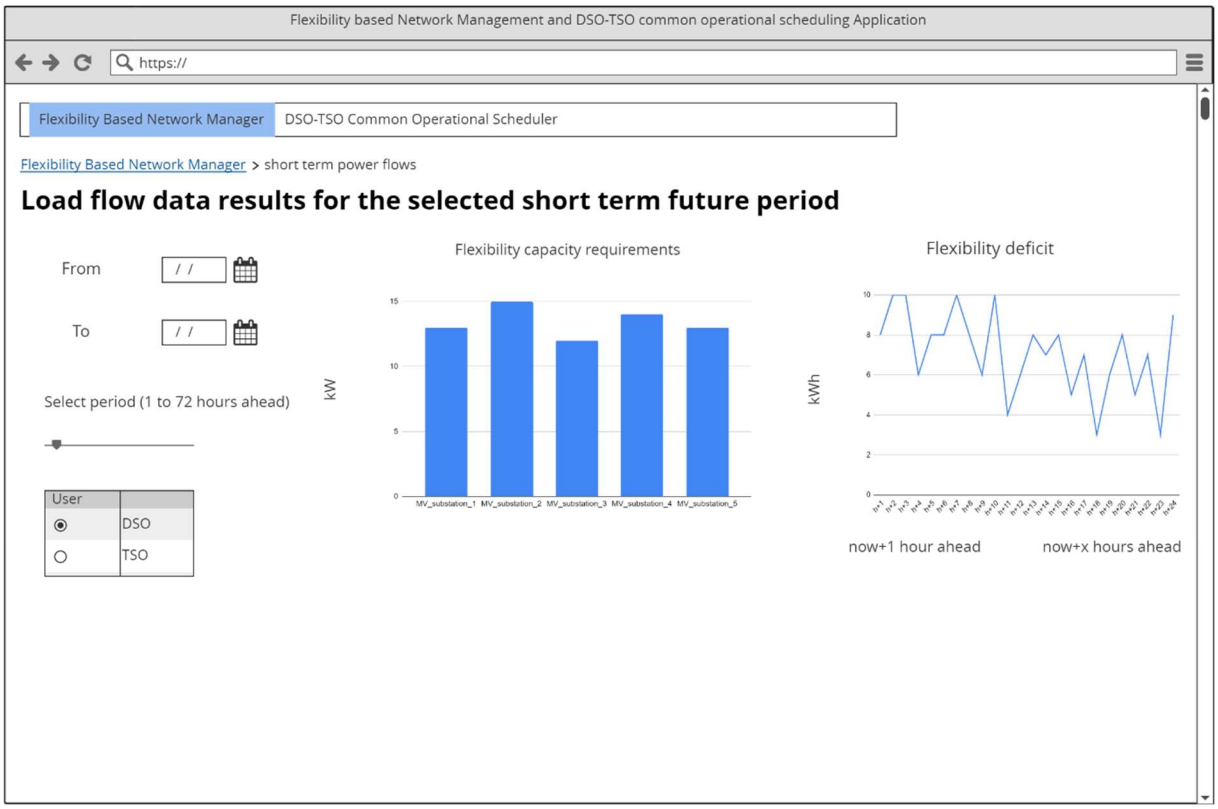

Figure 21: FBNM – load flow results mock up

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The next feature the user can be presented with, is a summary which lists the flexibility products in need. The user shall select the short-term period (intra-day to 3 days ahead) and a list with identified needs is displayed, indicating amounts of flexible demand needed, direction of flexibility, timeslots or periods of interest.

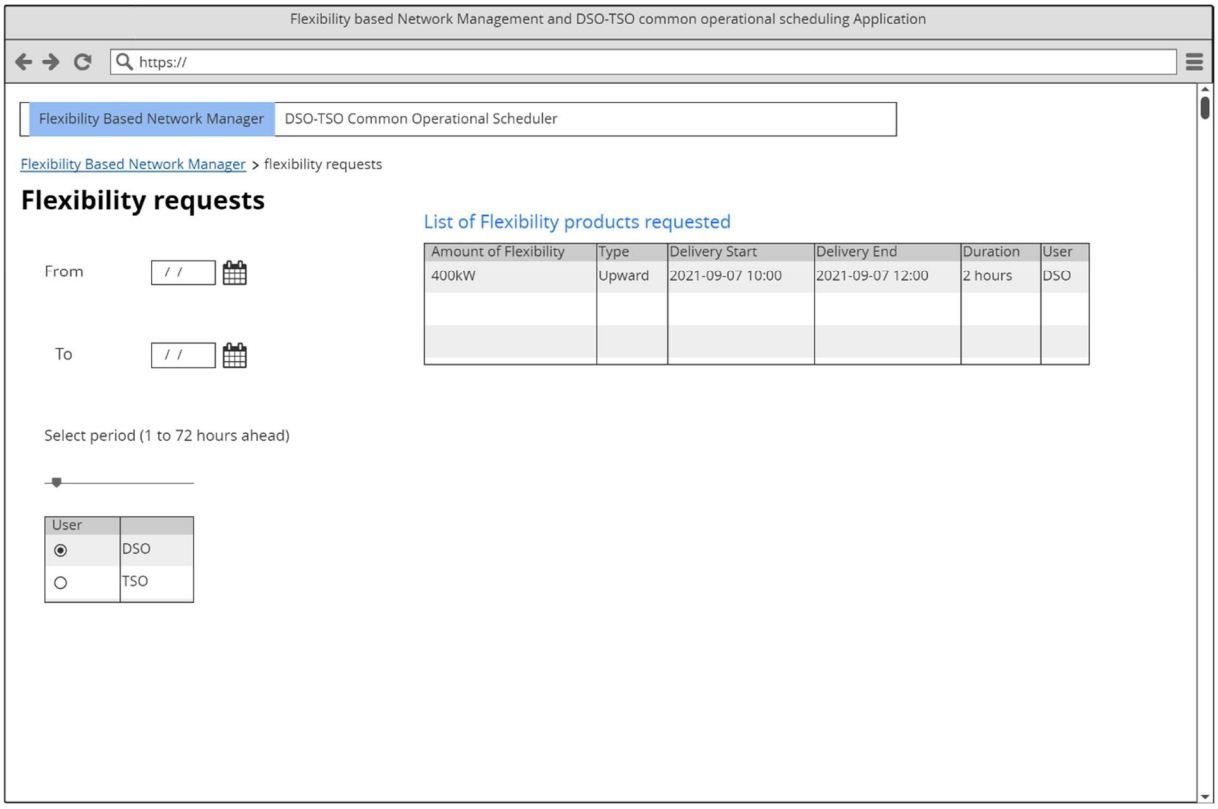

Figure 22: FBNM- display flexibility requests mock up

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At the short-term scheduling feature, the user shall select the dates of interest, the number of hours they want to look ahead and perform flexibility scheduling and the type of the grid service they refer to, congestion management service or balancing service. Thereinafter, they can view the resulting flexibility scheduling bids from the operator, with the resolution of displayed data adjusted from 15 minutes to hourly depending on the service in question.

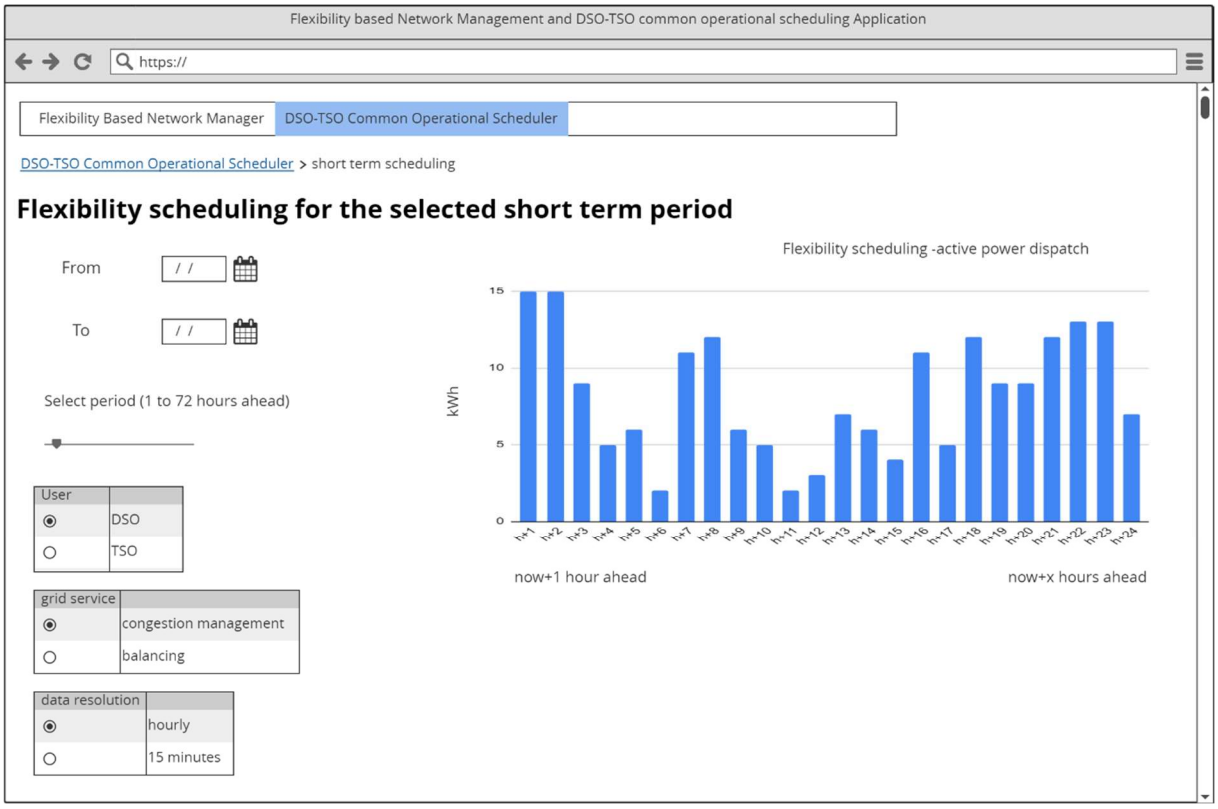

Figure 23: DSO-TSO Common Operational Scheduler- display short term flexibility scheduling

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Finally, the user can visualize any associated alerts from the resulting scheduling, such as conflicting requests between operators, or between different services and thereinafter the prioritization of those requests according to the adopted coordination scheme.

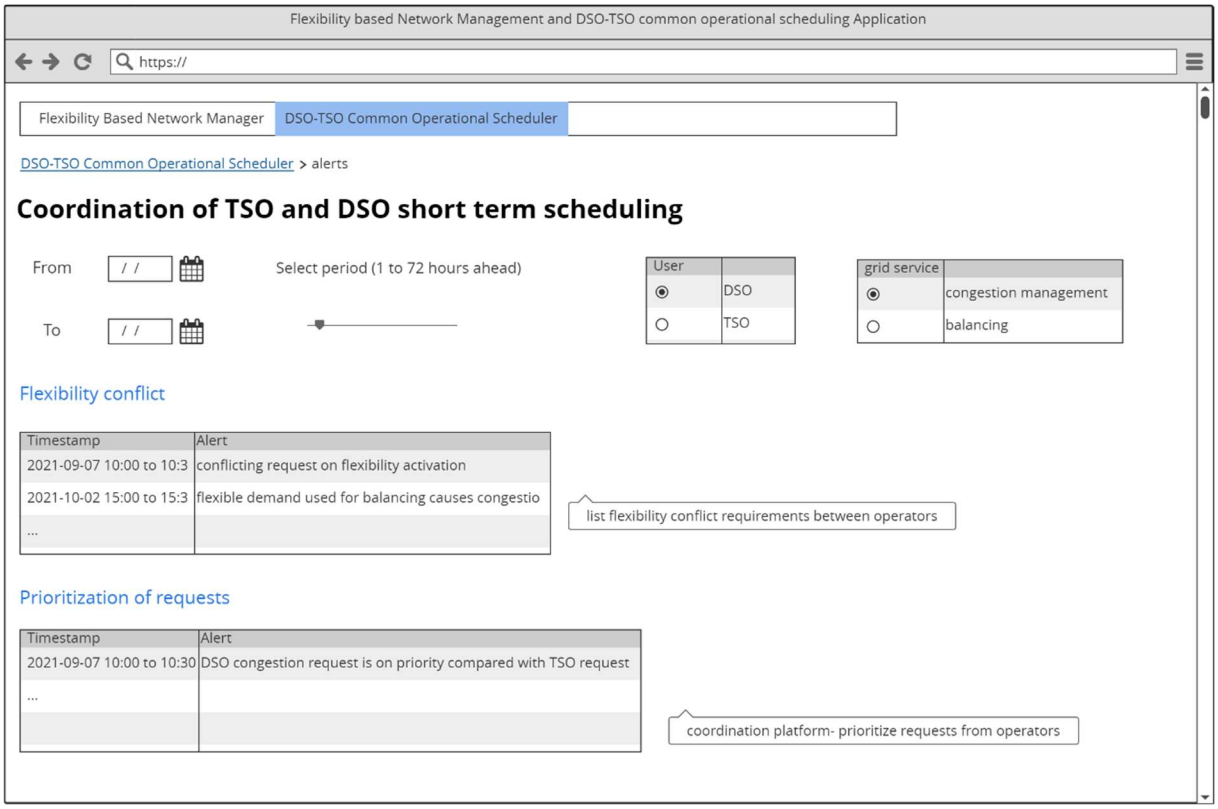

Figure 24: DSO-TSO Common Operational Scheduler- conflicts and prioritizations mock up

3.2.3 Exploited technology stack

In order to meet the requirements of the platform, Flexibility based Network Management and DSO-TSO common operational scheduling Application will be developed on state-of-the art technologies, namely: (a) in the back-end & the front-end layer, Django Web framework of Python for serving the components as an efficient, secure and scalable REST API, (b) in the data storage layer, SQL Server as the relational database for local power grid calculations, (c) in the application layer, Python programming language and its related libraries (pandapower, pygurobi, etc.) for fast and accurate power grid calculations.

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3.3 Performance monitoring and predictive maintenance application

The main aim of this innovative tool for the management of RES plants is ensuring their optimal operation, predictive maintenance and proactive avoidance of equipment faults. The tool steps on the forecasting and predictive analytics baseline algorithms (developed in WP4) and appropriate machine learning techniques towards identifying in real-time predictive maintenance needs, increasing PV technology reliability and efficiency and improving power trading functions on the plant operator side.

In summary, the tool allows for the proactive diagnosis of equipment faults and their characterization, enables the continuous monitoring of key power quality indicators, assesses the probability of fault occurrence and provides more accurate active/ reactive power forecasts, based also on the objective assessment of the PV plant assets' status and health. In addition, these forecasts feed into Retailers, DSOs and TSOs systems high-value information for either optimizing green power exchanges/ trading (retailers) or improving short-term operational scheduling.

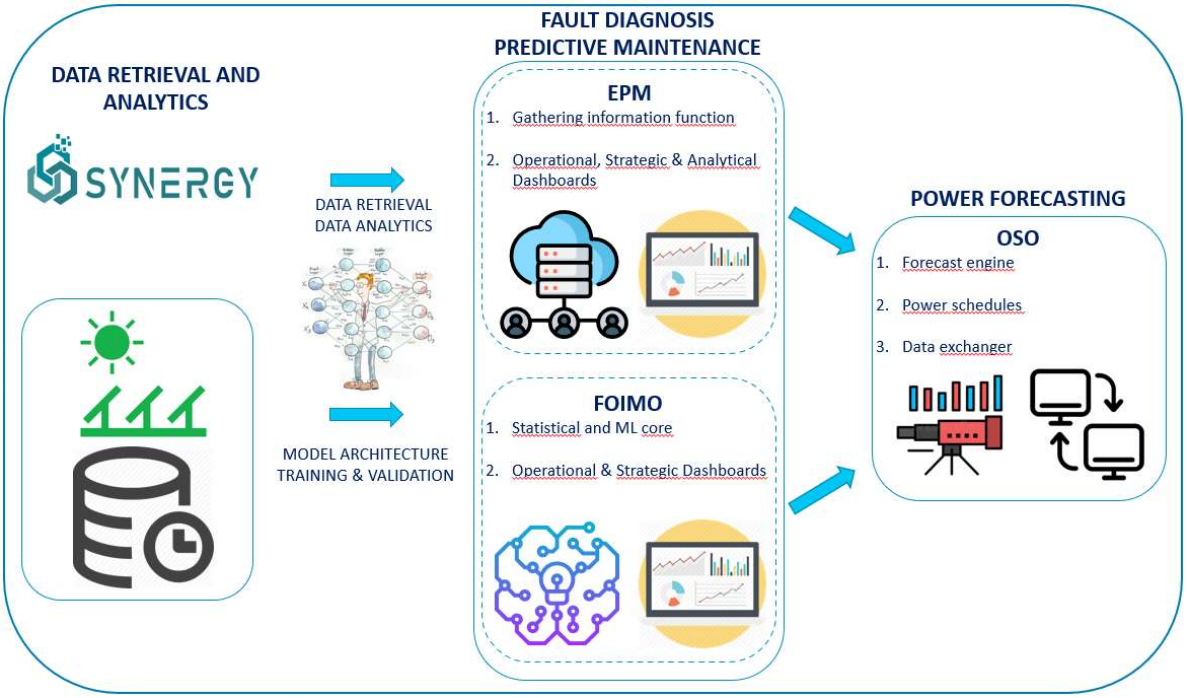

Figure 25: App Architecture including all its components and relationship with the SYNERGY Platform

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3.3.1 Component details

3.3.1.1 Enhanced Performance Monitor

The Enhanced Performance Monitor (EPM) module will be the control centre of the performance of a PV plant. It will consist of several dashboards showing the main production parameters and specific Key Performance Indicators (KPIs) defined and used to easily visualize the performance of the plant.

The structure of the EPM will have different layers going from the whole plant to the component level. In this way, the user will have the possibility of choosing different detail levels with a unified view. Four levels are foreseen, namely: Full plant, Generation Unit (Inverter level), String box and panel. The monitoring, reporting and analytical capabilities of the EPM will be similar for all these detail levels.

Regarding the EPM capabilities, they will be deployed using three different dashboards at each detail level: **operational** for real time and/or short-term monitoring, **strategic** for long term reporting and **analytical** for identifying trends and checking the historical performance.

The diagrammatic operation of this engine is shown in Figure 2626.

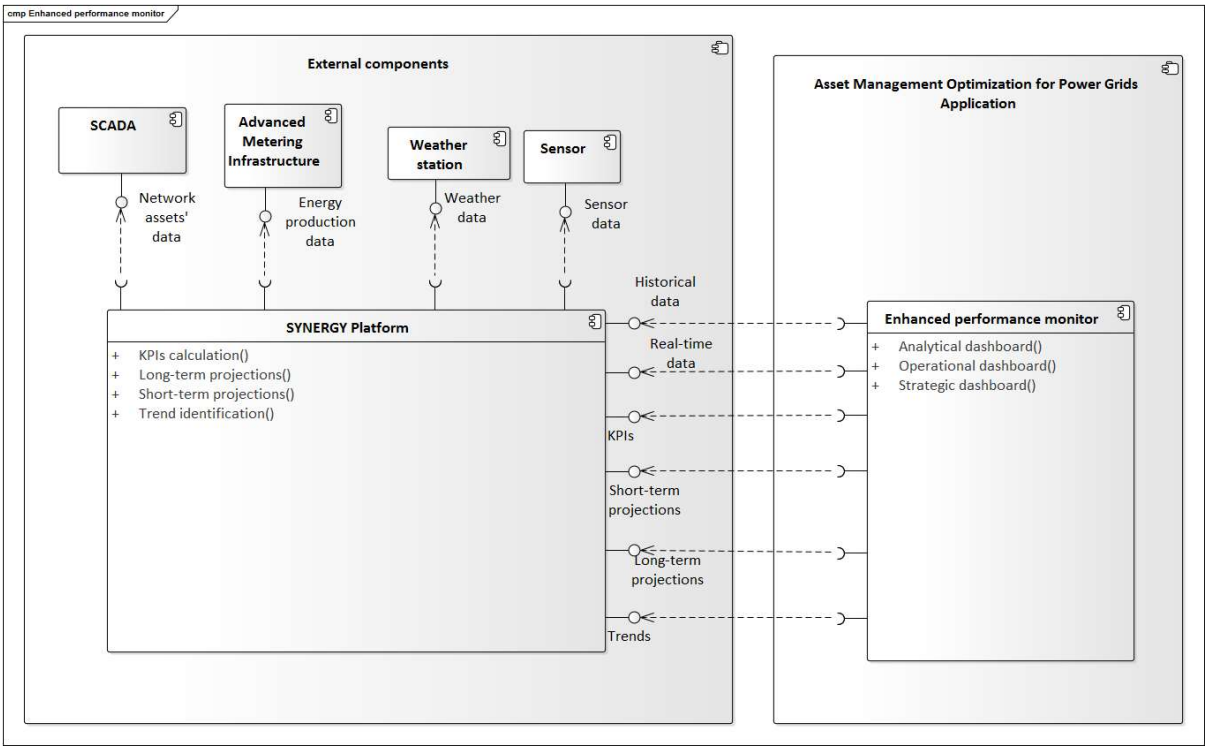

Figure 26: Enhanced Performance Monitoring Diagram

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More details on the features, data inputs/outputs and analytics to be performed by the component are provided hereby. The list of features offered by the Enhance Performance Monitor, as initially have been described in D2.6, includes:

Table 29: Features of Enhance Performance Monitor component

Feature	Description
EPM_1	Collecting information function: This function will aim to continuous collect and aggregate all information and variables coming from different data sources as Plant SCADA data base, meters, weather stations and locally deployed sensors, from the Synergy platform. This function will step on the baseline algorithms developed in WP4 and will complement them (if needed).
EPM_2	Operational dashboard: This dashboard will provide the visualization of the ongoing parameters and KPIs in real time or with a short-time horizon. This will allow to verify and control the performance of the asset in the day-to-day business. It will provide the possibility of displaying at the different detail levels included in the EPM: full plant, inverter level, string box and panel.
EPM_3	Strategic dashboard: the main aim of this functionality will be to report information from the EPM, mainly for long-term visualizations. It will allow to summarize the performance over set time frames: past month, quarter, or year, for example. Specific user defined time frames will also be possible. The reporting will be performed at the different detail levels included in the EPM.
EPM_4	Analytical dashboard: this dashboard will help to identify trends, compare them with multiple variables and create predictions, and targets, which can be implemented in the operation and maintenance of the plant. The analysis will be possible at all the detail levels included in the EPM. As with EPM_1, this functionality will mainly step on the baseline algorithms developed in WP4 and, if needed, will complement them in order to achieve the expected results.

The following tables provide a detailed view of the required data inputs, analytics that will be used on the available data and expected outcomes to cover the required functionalities.

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Table 30: Enhanced Performance Monitor data inputs

SCADA data	**Data relevant to assets under maintenance that is automatically retrieved from SCADA.** **The specific properties to be collected depend on the type of asset under maintenance.**
Expected update rate	15 minutes
Coverage	Assets under maintenance
Resolution	Minutes range
Weather and astronomical data	**Log with temperature, wind speed, solar radiation, sun position (elevation and azimuth angles)**
Expected update rate	Daily
Coverage	Assets under maintenance
Resolution	Minutes range
Locally deployed sensors	**Inverters and string boxes signals to have a deeper analytics of the asset performance.**
Expected update rate	15 minutes
Coverage	DC/AC voltage - DC/AC current
Resolution	Minutes range

A high-level identification of the input data is only provided at the stage since the deployment of the advanced monitoring equipment that will clarify certain, critical open points is currently ongoing in the demo sites. Along with the definition of input data, the list of analytics processes required by the component is defined in the following table:

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Table 31: Enhanced Performance Monitor analytics

Operational dashboard	**Visual representations of the operation conditions and performance of the plant, including conventional KPIs for PV plants (i.e. Performance Ratio).**
Required inputs	Operating variables datasets
Expected outputs	Operational Dashboards
Strategic dashboard	**Visual representations of strategic KPIs, specifically defined using the advance monitoring system (TBD).**
Required inputs	Operating variables or numerical values of strategic KPIs
Expected outputs	Strategic Dashboards
Analytic dashboard	**Visual representation of trends of strategic and operational variables, including historical data, in order to find un-tapped patterns.**
Required inputs	Operating variables datasets
Expected outputs	Analytic Dashboards

The analytics needed for several features will be designed and executed within the SYNERGY Platform and the outcomes are retrieved from the SYNERGY Platform by the app (as described in section 2.4). Details about the data assets offered by the SYNERGY Platform to be consumed and presented to end users in the UI of the Enhance Performance Monitor are presented in the following table:

Table 32: Enhanced Performance Monitor outcomes

Historical data	**Historical data retrieved from assets under maintenance (i.e. energy production at inverter level, temperature operation, DC current, DC intensity, tracker position if applicable, etc.)**
Expected update rate	According to monitoring capabilities
Coverage	Assets under maintenance

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Resolution	Minutes range
Real-time data	**Latest set of data available from assets under maintenance (i.e. energy production at inverter level, temperature operation, DC current, DC intensity, tracker position if applicable, etc.)**
Expected update rate	According to monitoring capabilities
Coverage	Assets under maintenance
Resolution	Minutes range
Asset health indicators	**Health score computed for each of the assets under maintenance**
Expected update rate	According to monitoring capabilities
Coverage	Assets under maintenance
Resolution	-

3.3.1.2 Fault Occurrence Inspector and Maintenance Optimizer

The Fault Occurrence Inspector and Maintenance Optimizer (FOIMO) module aims to introduce new approaches for fault diagnosis and predictive maintenance of PV plants, using the information collected by the EPM module. The core of the system is based on a set of statistical and Machine Learning (ML) algorithms ingesting data from the plant and looking for trend deviations, misclassifications, uncorrelations, etc. revealing component failures at the plant detail levels defined in the EPM.

The aim of the module is divided into three main tasks:

- Energy prediction for a selected time period using machine learning algorithms, for which the explanatory variables need to be inputted. These explanatory variables were selected among the set of variables monitored at the plant.
- Finding anomalies in the plant operation using recorded production data and the prediction coming from the machine learning model.

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- Forecast temporal trend of operation variables (i.e. energy, currents, voltage), at different levels of the plant and key components to identify potential failure risks and organise predictive maintenance actions to minimise any operation drop/fault.
- In addition, control charts and reliability indexes including, when possible, the probability of occurrence will allow the operator to anticipate possible failures in the components. Two dashboards, for facilitating visualization and reporting, will be developed too. The diagrammatic operation of this engine is shown in Figure 27.

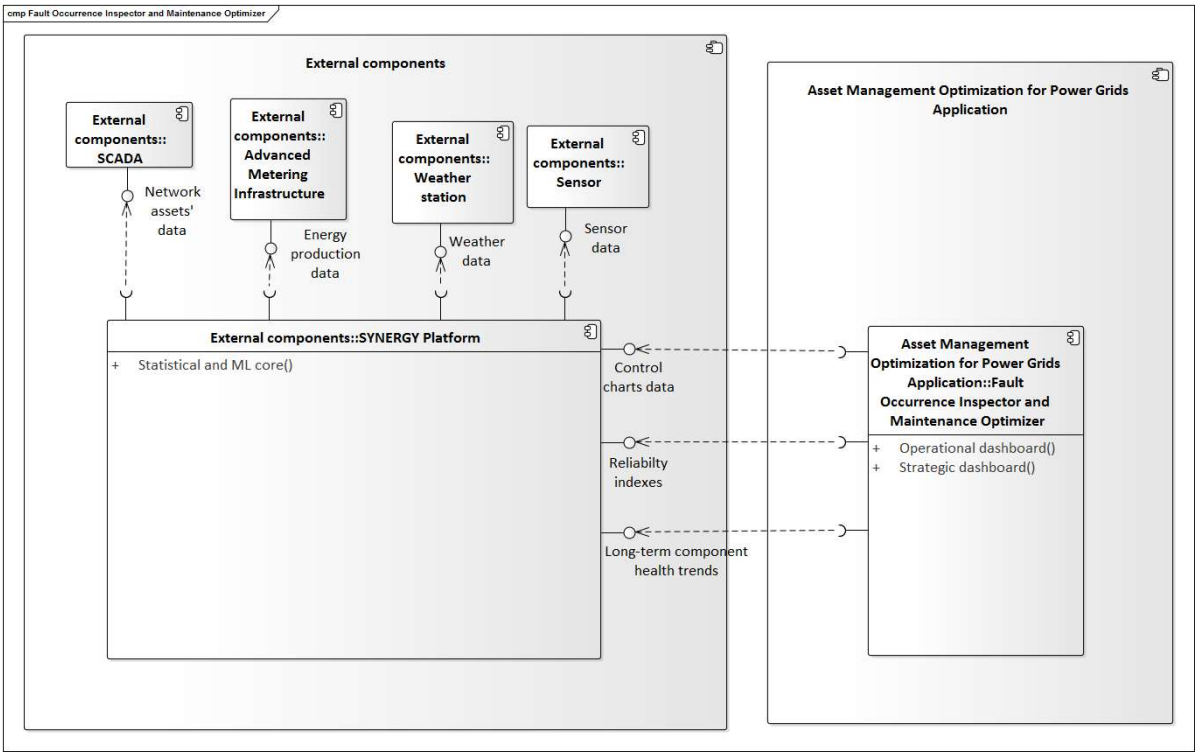

Figure 27: Fault Occurrence Inspector and Maintenance Optimizer Operation Diagram

More details on the features, data inputs/outputs and analytics to be performed by the component are provided hereby. The list of features offered by FOIMO, as initially have been described in D2.6, includes:

Table 33: Features proposed for the Fault Occurrence Inspector and Maintenance Optimizer

Feature	Description
FOIMO_1	**Statistical and Machine Learning core:** This is the main feature of the module that will be essentially supported by the SYNERGY Big Data Platform & AI

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	Marketplace. Based on the development and test of different statistical and machine learning algorithms, the aim of this functionality is to identify plant anomalies and operating failures, which would help to apply a predictive maintenance procedure to the plant. This would lead to a reduction of the O&M costs whilst increasing the energy production due to a minimisation of the losses caused by any failure not foreseen. The final output of the model, as well as control charts will be displayed on the dashboards of the tool (FOIMO_2 and FOIMO_3), as it can be seen in Figure 31 and Figure 32. The plant operator could therefore react to any anomaly/failure occurring in the plant with a short response time, thus limiting the production losses. In addition to this functionality, the FOIMO_1 will analyse the trends of the production variables (energy, voltage, current, etc.) and the reliability indexes (KPIs) with the aim of identifying potential risks and failures on the different levels of the plant. This tool will help the plant operator to schedule the main maintenance activities (predictive maintenance).
FOIMO_2	**Operational dashboard:** this dashboard will provide the visualization of the control charts and reliability indexes at the different detail levels defined in the EPM. This will allow to component failures in the day-to-day business.
FOIMO_3	**Strategic dashboard:** this will be the reporting tool of the FOIMO, mainly for long-term visualizations. It will allow to summarize the detected failures and to identify long-term trends indicating the evolution of the health of the components. The reports will be obtained at the different detail levels included in the EPM.

The following tables provide a detailed view of the required data inputs, analytics that will be used on the available data and expected outcomes to cover the required functionalities.

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Table 34: Fault Occurrence Inspector and Maintenance Optimiser data inputs

SCADA data	**Data relevant to assets under maintenance that is automatically retrieved from SCADA.** **The specific properties to be collected depend on the type of asset under maintenance.**
Expected update rate	15 minutes
Coverage	Assets under maintenance
Resolution	Minutes range
Weather and astronomical data	**Log with temperature, wind speed, solar radiation, sun position (elevation and azimuth angles)**
Expected update rate	Daily
Coverage	Assets under maintenance
Resolution	Minutes range
Power plant event/alert log	**Log with the occurrence of different kind of events/alerts, bound to their location and time of occurrence**
Expected update rate	Daily
Coverage	Assets under maintenance
Resolution	-
Measurements taken by maintenance personnel	**For some assets there is no availability of remote monitoring nor access to the local datalogger. Thus, maintenance personnel is in charge of manually collecting the relevant measurements (i.e. energy production, solar radiation, etc.)**
Expected update rate	Upon scheduled inspection

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Coverage	Assets under maintenance
Resolution	-

Along with the definition of input data, the list of analytics processes required by the component is defined in the following table:

Table 35: Fault Occurrence Inspector and Maintenance Optimiser analytics

Asset production anomalies	**Determine potential anomalies on the production in previous time steps**
Required inputs	Historic production and meteorologic data; current meteorological variables and production data
Expected outputs	Alert control charts with potential anomalies in production
Maintenance advisor	**Determine the probability of failure in the short-term**
Required inputs	Run-to-failure datasets covering addressed asset type, issue type and time range
Expected outputs	Normalised trends and operational threshold

The analytics needed for several features will be designed and executed within the SYNERGY Platform and the outcomes are retrieved from the SYNERGY Platform by the app (as described in section 2.4). Details about the datasets offered by the SYNERGY Platform to be consumed and presented to end users in the UI of the Fault Occurrence Inspector and Maintenance Optimiser are presented in the following table:

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Table 36: Fault Occurrence Inspector and Maintenance Optimiser outcomes

Control charts and KPIs calculation (short-term)	**Normalised temporal trend of key variables for each specific device analysed, and failure probability estimation for each asset within a pre-defined time horizon.**
Expected update rate	Daily
Coverage	Asset type Issue type
Resolution	-
Early alerts	**Alert predictions of anomalies on the performance of the plant and failures that may take place in near future**
Expected update rate	Hourly
Coverage	Assets' maintenance
Resolution	-

3.3.1.3 Operational Scheduling Optimizer

The Operational Scheduling Optimizer (OSO) will be responsible for forecasting the energy production for different time horizons, for large PV plants.

The OSO will use climatic and operating variables previously tested and selected in the FOIMO as input. Differently to FOIMO, which used data coming from the climatic stations to predict the energy production, the OSO will use weather forecast in order to anticipate the energy production. The OSO will output an energy production time profile for the time step defined. This will allow the characterisation of the energy production profile within a certain time range in advance using the pre-trained machine learning model.

The diagrammatic operation of the OSO engine is shown in Figure 28.

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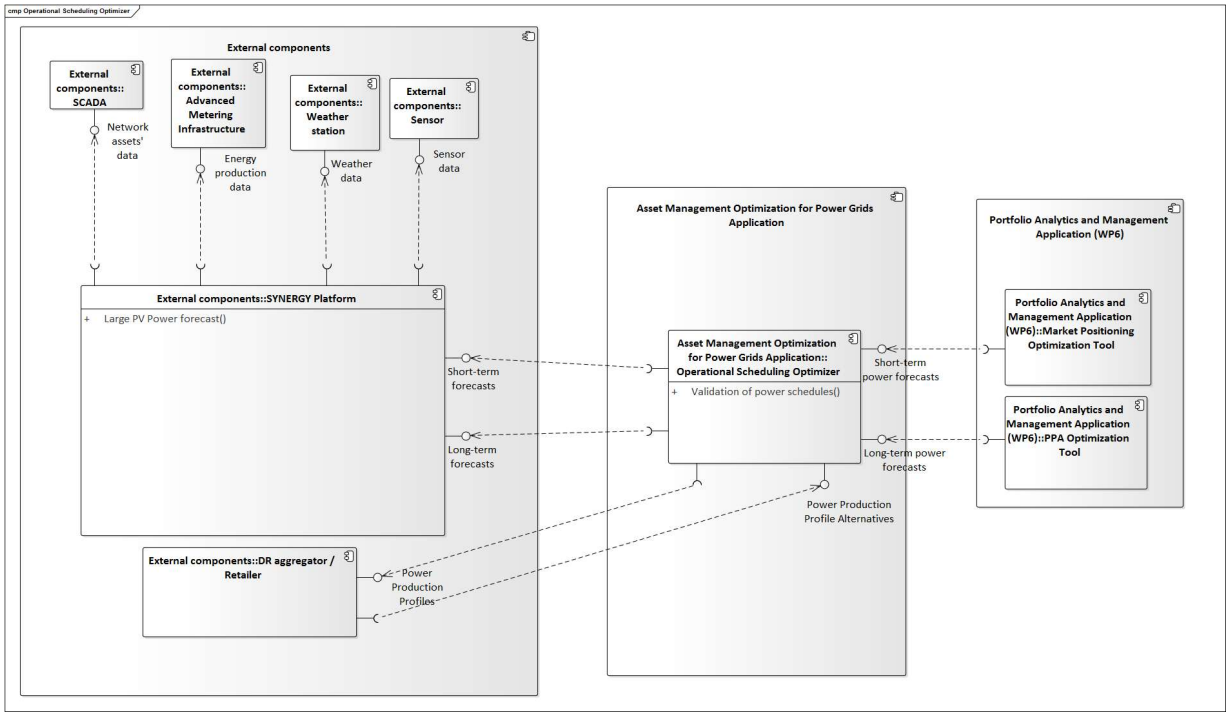

Figure 28: Operation Schedule Optimizer Operation Diagram

More details on the features, data inputs/outputs and analytics to be performed by the component are provided hereby. The list of features offered by OSO, as initially have been described in D2.6, includes:

Table 37 : Features of the Operation Schedule Optimizer Operation

Feature	Description
OSO_1	Large PV power forecast engine: As aforementioned, the machine learning model developed in FOIMO will be used. This model will be pre-trained with historic data. Thus, the model will input forecast of the climatic variables for the time horizon defined, for which the energy production will be forecasted. Among others climatic variables, the horizontal solar radiation or wind speed will be used. The forecasts will be configured in the SYNERGY Platform and retrieved for the app's needs.
OSO_2	Validation of power schedules function: this function will help RES operators to validate if the Power Production Profiles proposed by DR aggregators or Retailers

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	are technically feasible. In case the plant cannot assume such production profiles, this function will provide a feasible alternative.
OSO_3	Data exchanger with Wholesale Market Participation Decision Support System App through the SYNERGY Platform: for the optimized energy bidding and output sharing in wholesale markets, OSO_3 will share the required inputs (power forecast) to identify portions of the energy forecasted that could be included in the Day ahead market and in the other markets using short term forecasts.
OSO_4	Data exchanger with Portfolio Pattern Forecasting Engine App through the SYNERGY Platform: for the Optimized energy bidding and output sharing in PPAs, OSO_4 will share the required inputs (power forecast) to identify portions of the energy forecasted that could be included in long-term PPAs with energy retailers.

The following tables provide a detailed view of the required data inputs, analytics that will be used on the available data and expected outcomes to cover the required functionalities.

Table 38: Operational Scheduling Optimiser data inputs

SCADA data	**Data relevant to assets under maintenance that is automatically retrieved from SCADA.** **The specific properties to be collected depend on the type of asset under maintenance.**
Expected update rate	15 minutes
Coverage	Assets under maintenance
Resolution	Minutes range
Weather and astronomical data	**Log with temperature, wind speed, solar radiation, sun position (elevation and azimuth angles)**
Expected update rate	Daily

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Coverage	Assets under maintenance
Resolution	Minutes range
DR aggregator/Retailer	**Power production profiles to be followed in the PV plant, once the biding process has finished, in order to allocate them on the correct market fraction (day ahead, intra-day, etc.).**
Expected update rate	Daily
Coverage	Assets under maintenance
Resolution	Minutes range

Along with the definition of input data, the list of analytics processes required by the component is defined in the following table:

Table 39: Operational Scheduling Optimiser analytics

Power production profile	**Determine the production profiles and confirm they can be achieved**
Required inputs	Meteorological data for the time scope desired
Expected outputs	Power production profile
Short-term expected production	**Determine the short-term PV production of the asset to define the scopes for the different fractions**
Required inputs	Meteorological data for the time scope desired
Expected outputs	Power production data and profile
Long-term expected production	**Determine the long-term PV production of the asset to optimise PPAs**

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 872734.

Required inputs	Meteorological data forecast for the time scope desired
Expected outputs	Power production data

The analytics needed for several features will be designed and executed within the SYNERGY Platform and the outcomes are retrieved from the SYNERGY Platform by the app (as described in section 2.4). Details about the datasets offered by the SYNERGY Platform to be consumed and presented to end users in the UI of the Operational Scheduling Optimiser are presented in the following table:

Table 40: Operational Scheduling Optimiser outcomes

Short-term expected production	**Day ahead power forecast according to weather forecasts used and the real SoH of the plant**
Expected update rate	Daily
Coverage	Asset
Resolution	Minutes range
Long-term production	**Yearly power forecast according to TMY**
Expected update rate	Daily
Coverage	Assets
Resolution	Hourly
Feasibility alternative for daily PPP	**Feasibility alternative for the power production profile**
Expected update rate	Daily
Coverage	Assets
Resolution	Minutes range

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 872734.

Optimised PPA agreements	**Long-term PPAs with the energy retailers**
Expected update rate	Daily
Coverage	Assets
Resolution	Hourly

3.3.2 User stories

A preliminary design of the interface of the three functionalities of the tool to be developed for the Advanced Performance Monitoring/ Forecasting and Predictive Maintenance for Large-scale RES plants has been carried out. The tool will require of a database which will be retrieved from the SYNERGY Platform, as well as some basic information of the plant location (i.e. latitude and longitude). Then, the users will select the function to be used, among which are included: Operational Dashboard, Anomalies Detection and Predictive Maintenance, Nowcast and Short-Term Forecast and Long-Term Forecast.

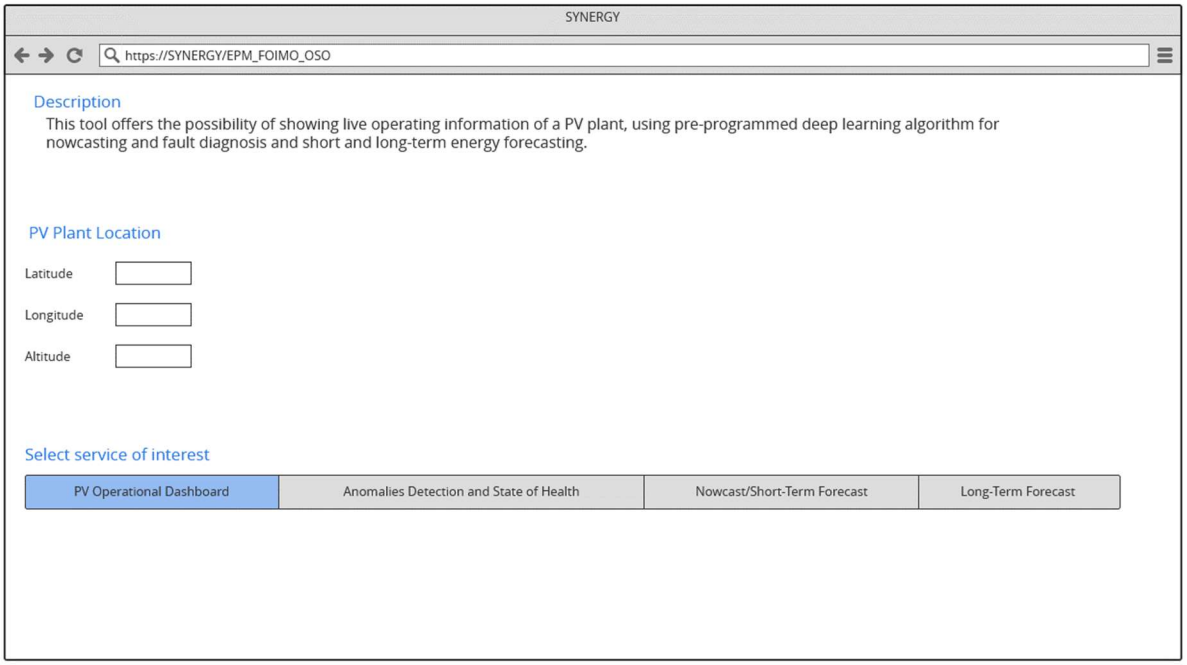

Figure 29: Introductory page

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The PV Operational Dashboard covers the frame of the EPM module, returning visual results of the set of variables included in the different data assets, which will be retrieved from the SYNERGY Platform. A chart outputting the daily production or the total production for the time interval selected will be also included.

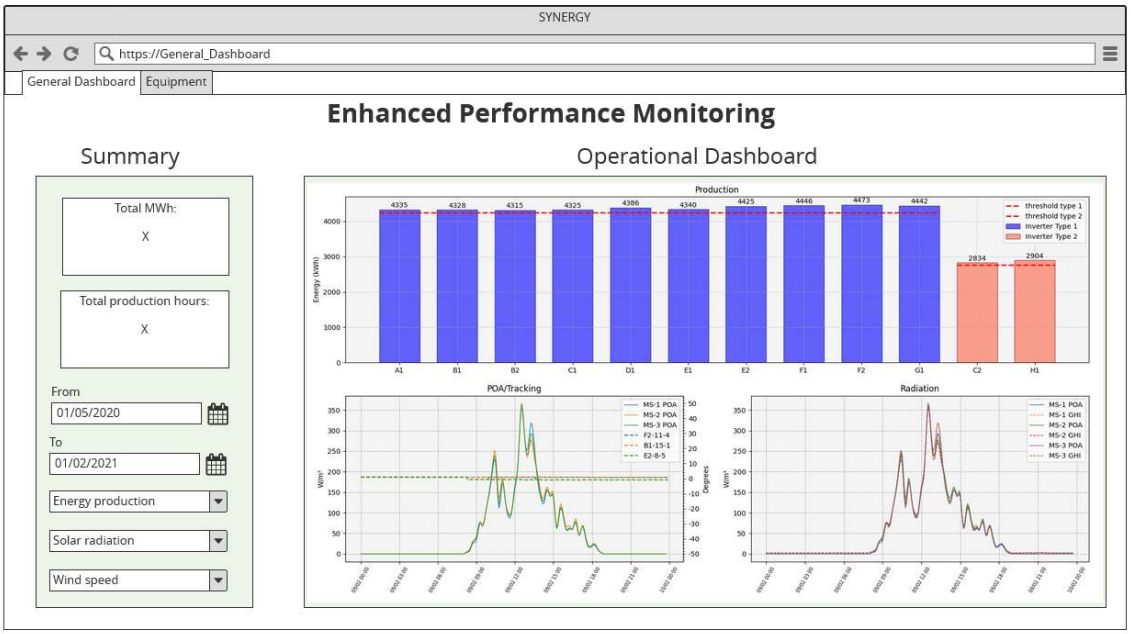

Figure 30: Enhanced Performance Monitor mock-up

A second window will show the real-time production vs the real-time forecast obtained from the machine learning model, identifying production shortfalls and, in case of anomaly, outputting a fault occurrence probability matrix for the main devices of the PV plant. Furthermore, the health status of the different devices may be also shown in order to help scheduling the maintenance based on the actual conditions of the equipment.

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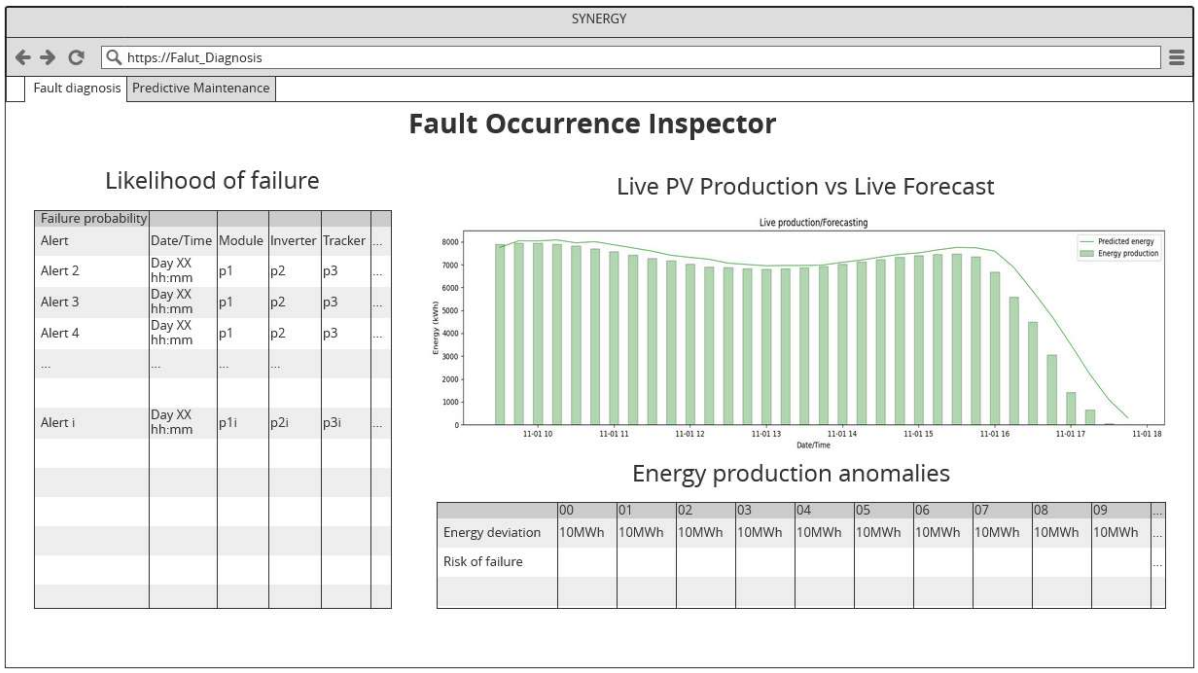

Figure 31: Fault occurrence inspector and maintenance optimizer

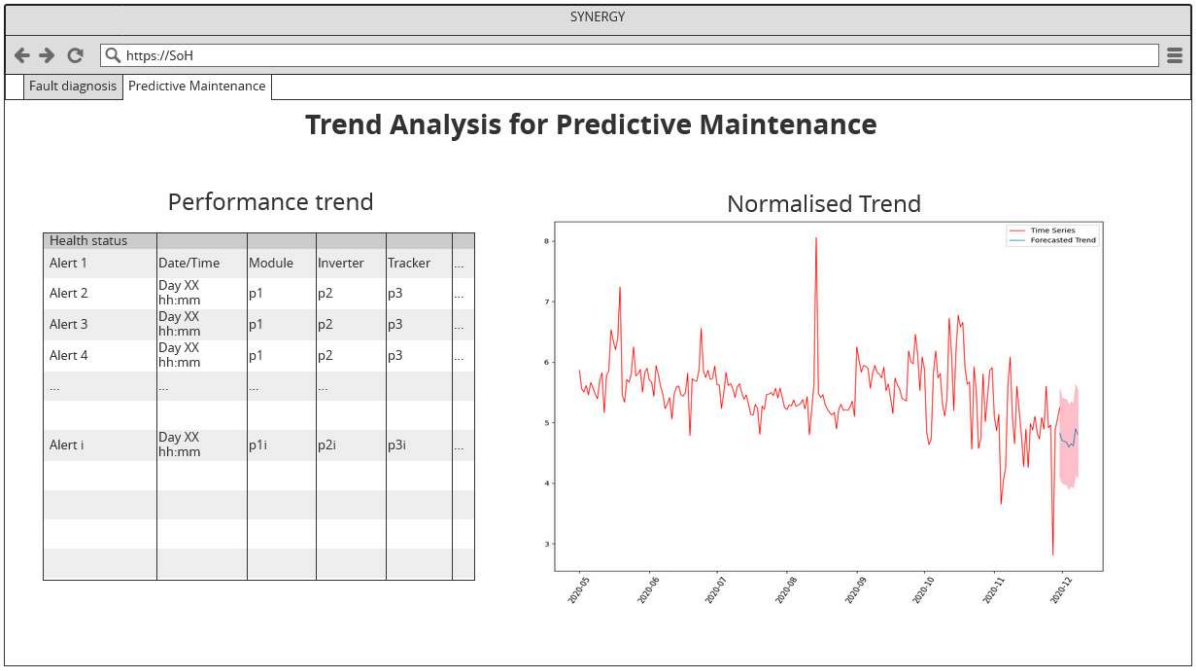

Figure 32: Fault occurrence inspector and maintenance optimizer mock-up

The nowcast and short-term forecast will show the results obtained by the machine learning model for a time-spam defined by the user. Climatic information forecast will be required to be inputted. A visual profile of the plant operation will be provided. A possibility to be included in the graphic results will be to overlap the forecast with the real-time production in order to check the deviation of the predictions.

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The short-term forecast could be then used by DSOs in order to allocate the energy production in each timestep for different purposes/markets by connecting this function with the functions developed in T6.1 through the SYNERGY Platform.

Regarding the long-term forecast, the climatic information for the time desired is needed. The platform will return a production profile for the time spam inputted. In addition, the predictions could be downloaded in csv file. This window will have the option of connect with the T6.1 through the SYNERGY Platform, providing the long-term profile to retailers, which will help when negotiating the PPAs.

Finally, the tool will compare the energy production profile with the required by DR aggregators or retailers, validating that both profiles match or rejecting it in case the production forecast does not fulfil with the required.

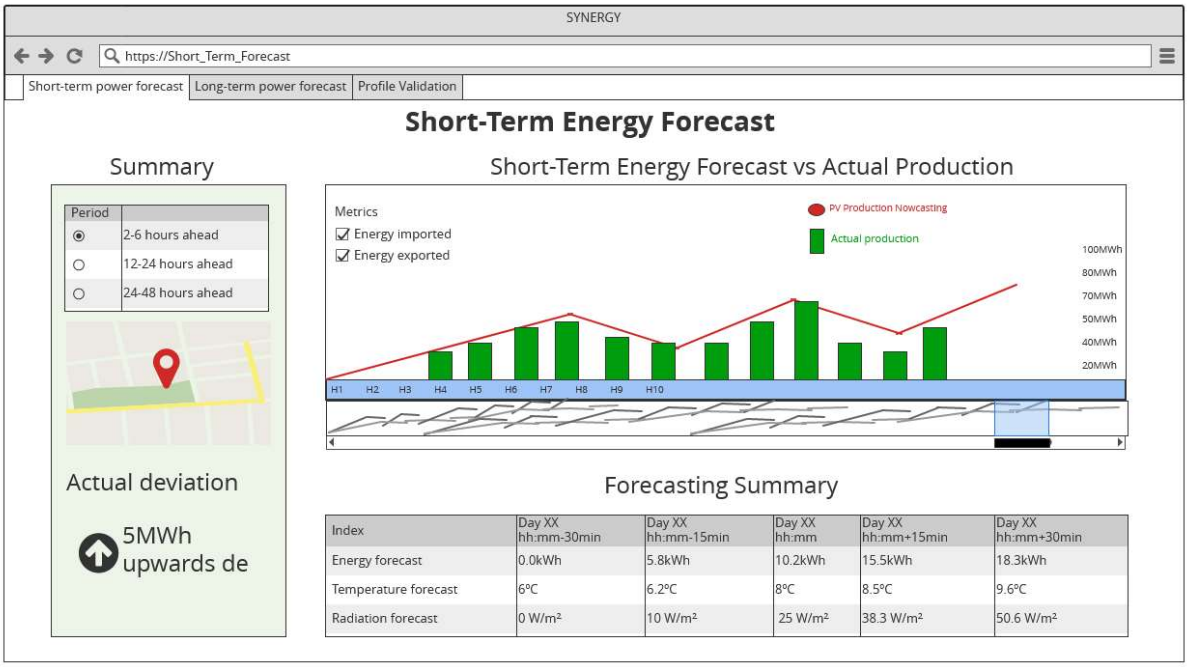

Figure 33: Operational Scheduling Optimizer mock-up

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 872734.

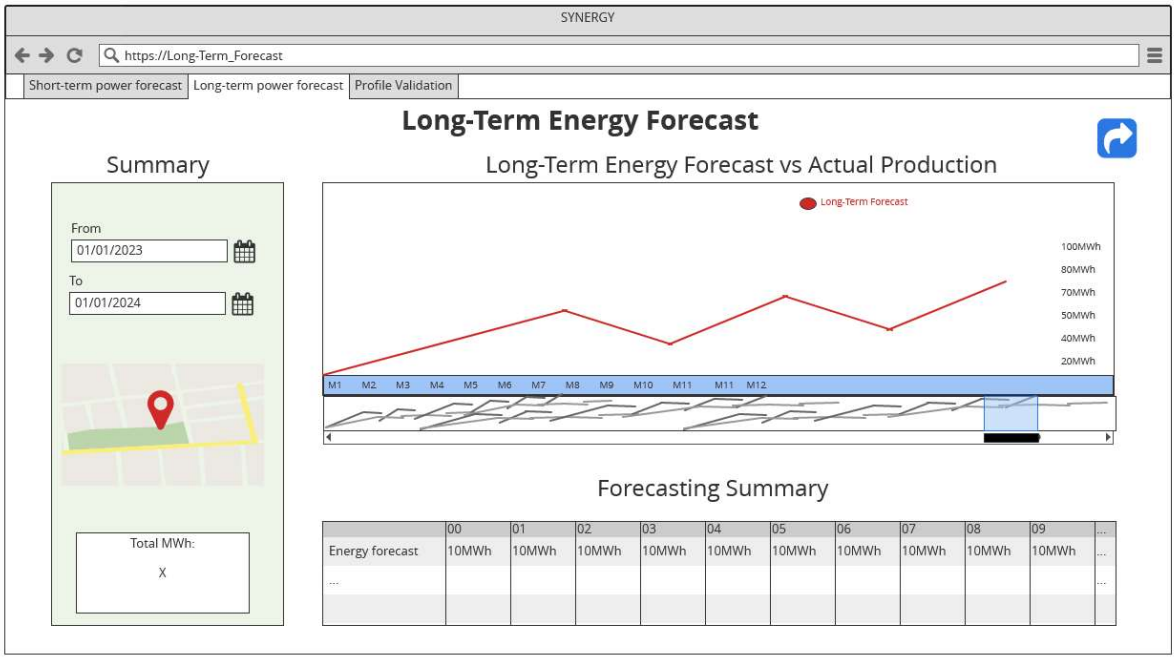

Figure 34: Operational scheduling optimizer mock-up

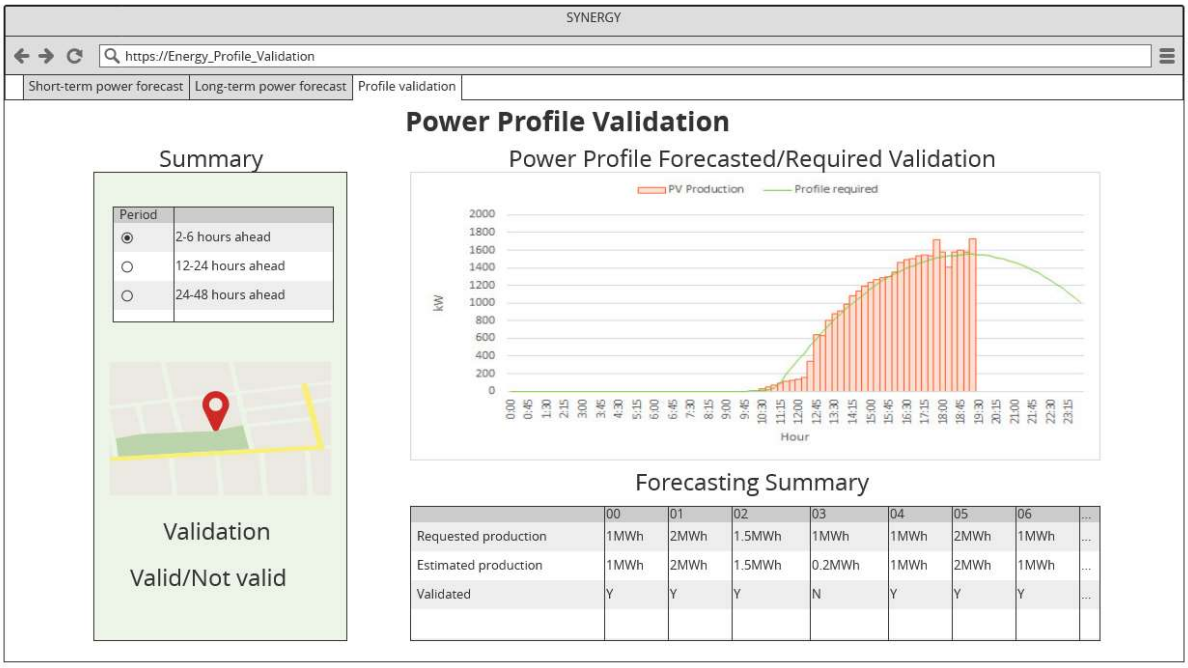

Figure 35: Operational Scheduling Optimizer mock-up

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3.3.3 Exploited technology stack

As stated also in D2.6, in order to provide its intended functionalities, the Advanced Performance Monitoring/ Forecasting and Predictive Maintenance for Large-scale RES plants will build on state-of-the art technologies, namely: With regards to the software libraries and platforms foreseen for the development of the user interface, those include NodeJS for backend services, Meteor for front-end/back-end communication and reactive data delivery to clients, and React for reusable and highly modular front-end development. In order to host component-specific data, MongoDB database will be used; in the data storage layer, depending on the applicable data assets' licenses (that determine whether local storage will be eventually allowed), PostgreSQL (as the relational database for the operational data of the application). The data analytics and optimizations libraries to be used in the application will be aligned with the frameworks and libraries that will be supported in the Data Analytics Services Bundle in the SYNERGY Cloud Platform. More specifically, Python and its main libraries for Data Analytics will be used, such as Pandas, Scikit-Learn, TensorFlow or Keras.

3.4 Asset management optimization application

The *Asset Management Optimization for Power Grids Application* implements different features that target the maintenance responsible operators of DSOs and TSOs, with the objective of providing different models that optimize the maintenance management by enriching the available data with the results of a number of analytics and forecasts.

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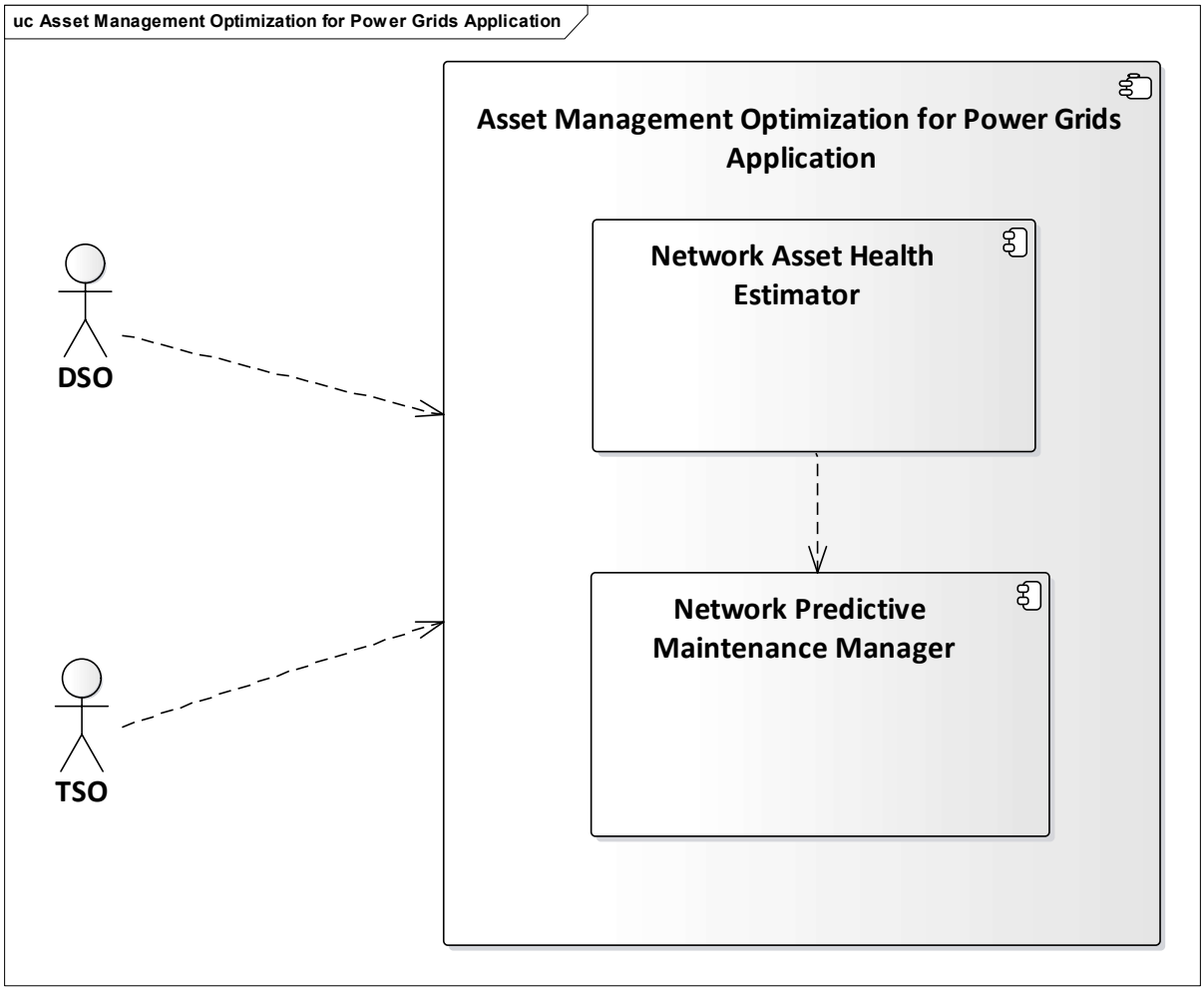

Figure 36: Asset Management Optimization for Power Grids Applications components and actors

The *Network Asset Health Estimator* component will, based on the different measurements available for a given asset type, model the overall health score of each asset instance under maintenance, providing automated assistance in the evaluation of asset status by maintenance staff, and an additional indicator to properly prioritize the scheduled maintenance operations.

The *Network Predictive Maintenance Manager* component will provide models to forecast failures of assets, based on the flows of data monitored from those assets and by considering also the effect of cascading effects (i.e. how an asset can be indirectly affected by failures detected on other assets of the grid)

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3.4.1 Component details

3.4.1.1 Network Asset Health Estimator

The Network Asset Health Estimator component will make use of the SYNERGY Platform to analyse a variety of network asset data sources towards the estimation of metrics that provide indications about the status of the different assets subject to maintenance, thus complementing Maintenance Management Systems with valuable information that will allow network operators to schedule the maintenance actions optimally.

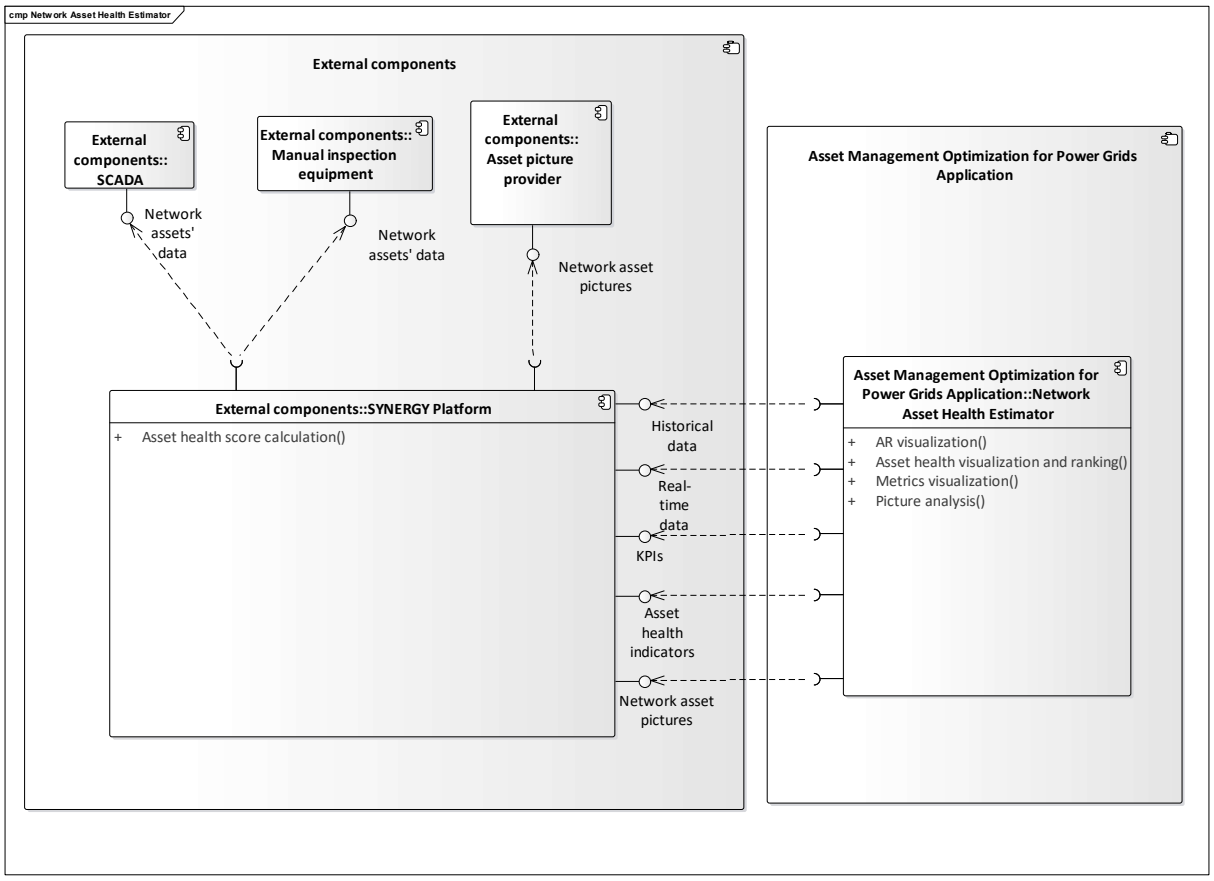

Figure 37 Network Asset Health Estimator component diagram

As depicted in the component diagram, this component will make use of as much measurements as possible from the assets under maintenance in order to train models able to provide a health score based on the last set of measurements available. The application will cover both measurements that come from telemetered assets, as well as measurements manually uploaded to the platform upon

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manual inspection of the assets. Additionally, available pictures will be processed to generate additional information about the assets under maintenance.

Three main types of analytics will be used to provide the expected results:

- Picture analysis to extract information of the out of the available pictures that enriches and complements available measurements.
- Classification models that provide a health score based on the latest available set of measurements.
- Sequence prediction models that provide early alerts by forecasting future events, according to the evolution of the alert log provided by the SCADA system.

These analyses will provide as a final result a health indicator for each asset under maintenance.

The list of features offered by the Network Asset Health Estimator as specified in the reference architecture document includes:

Table 41: Network Asset Health Estimator features

Feature	Description
NCHE_1	Picture analysis: available network asset pictures managed by the network operator, including infrared pictures, will be analysed by Computer Vision algorithms in order to extract relevant metrics, such as temperature, person presence or smoke presence. These metrics will be used to enrich the available information of the assets under maintenance
NCHE_2	Metrics visualization: for all available metrics, this component will provide appropriate graph visualizations to support the maintenance operator work
NCHE_3	Asset health score calculation: by taking into account the specification of each type of asset under maintenance and the available data, a high-level health score will be provided, allowing the maintenance operator to rank the assets accordingly and use this information in the maintenance scheduling
NCHE_4	Presentation of results by means of a mobile AR visualization system: Augmented Reality visualization of the information managed by this component, explored in

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	order to provide maintenance operators with novel means of accessing information, which will enhance their user experience

The following tables provide a detailed view of the required data inputs, analytics that will be used on the available data and expected outcomes to cover the required functionalities.

Table 42: Network Asset Health Estimator data inputs

SCADA data	**Data relevant to assets under maintenance that is automatically retrieved from SCADA.** **The specific properties to be collected depend on the type of asset under maintenance. This component is data agnostic since it will be used for classification/profiling purposes. All available data will be considered for this purpose**
Expected update rate	Near real-time
Coverage	Assets under maintenance
Resolution	Seconds-Minutes range
Infrared pictures	**Infrared pictures provide valuable information for maintenance about the temperature of certain assets**
Expected update rate	Upon scheduled inspection
Coverage	Assets under maintenance
Resolution	-
Drone pictures	**Drone pictures provide valuable information for maintenance for visual inspection, about visible damage or operation conditions of certain assets**
Expected update rate	Upon scheduled inspection
Coverage	Assets under maintenance

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Resolution	-
Measurements taken by maintenance personnel	**For some assets lacking availability of remote monitoring, maintenance personnel is in charge of manually collecting the relevant measurements** **This component is data agnostic, since it will be used for classification/profiling purposes. All available data will be considered for this purpose**
Expected update rate	Upon scheduled inspection
Coverage	Assets under maintenance
Resolution	-

Along with the definition of input data, the list of analytics processes required by the component is defined in the following table:

Table 43: Network Asset Health Estimator analytics

Asset health score calculation	**Based on the latest available measurements, the asset will be classified under a certain health score/level** **For this purpose, a supervised learning classification algorithm will be trained with historical information of asset inspections**
Required inputs	Dataset including measurements of similar assets and resulting health score assessment (for model preparation) Fresh measurements for asset under maintenance
Expected outputs	Current State of Health of asset under maintenance

Details about the datasets offered by the SYNERGY Platform to be consumed and presented to end users in the UI of the Network Asset Health Estimator are presented in the following table:

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Table 44: Network Asset Health Estimator analytics outcomes

Historical data	**Historical data retrieved from assets under maintenance.** **The specific properties to be provided depend on the type of asset under maintenance, and may potentially include electrical parameters - voltage, current, (re)active power, frequency… -, environmental parameters – temperature, humidity… – or mechanical asset-specific parameters. All available data will be considered for this purpose**
Expected update rate	According to monitoring capabilities (near real-time/upon scheduled inspection)
Coverage	Assets under maintenance
Resolution	Seconds/Minutes range (if telemetered)
Real-time data	**Latest set of data available from assets under maintenance.** **The specific properties to be provided depend on the type of asset under maintenance, and may potentially include electrical parameters - voltage, current, (re)active power, frequency… -, environmental parameters – temperature, humidity… – or mechanical asset-specific parameters. All available data will be considered for this purpose.**
Expected update rate	According to monitoring capabilities (near real-time/upon scheduled inspection)
Coverage	Assets under maintenance
Resolution	-
Picture-based indicators	**Data extracted from pictures. These indicators may include temperature metrics, presence indicators, smoke indicators.**
Expected update rate	Upon scheduled inspection
Coverage	Assets under maintenance

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Resolution	-
Asset health indicators	**Health score computed for each of the assets under maintenance**
Expected update rate	According to monitoring capabilities (near real-time/upon scheduled inspection)
Coverage	Assets under maintenance
Resolution	-

Additionally, the Network Asset Health Estimator component will implement the following analytics:

Table 45: Network Asset Health Estimator analytics

Picture analysis	**Extract relevant metrics from picture sources.** **Generic metrics are proposed. This particular function can be further extended to address particular end-user requirements**
Required inputs	Infrared pictures Drone pictures
Expected outputs	Temperature Presence Smoke

3.4.1.2 Network Predictive Maintenance Manager

The Network Predictive Maintenance Manager component will analyse a variety of network component data sources, including those metrics provided by the Network Component Health Estimator, with the objective of complementing Maintenance Management Systems with estimations

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of the probability to failure of single network assets in different time frames. This information will support network maintenance operators in the optimal scheduling of the maintenance actions.

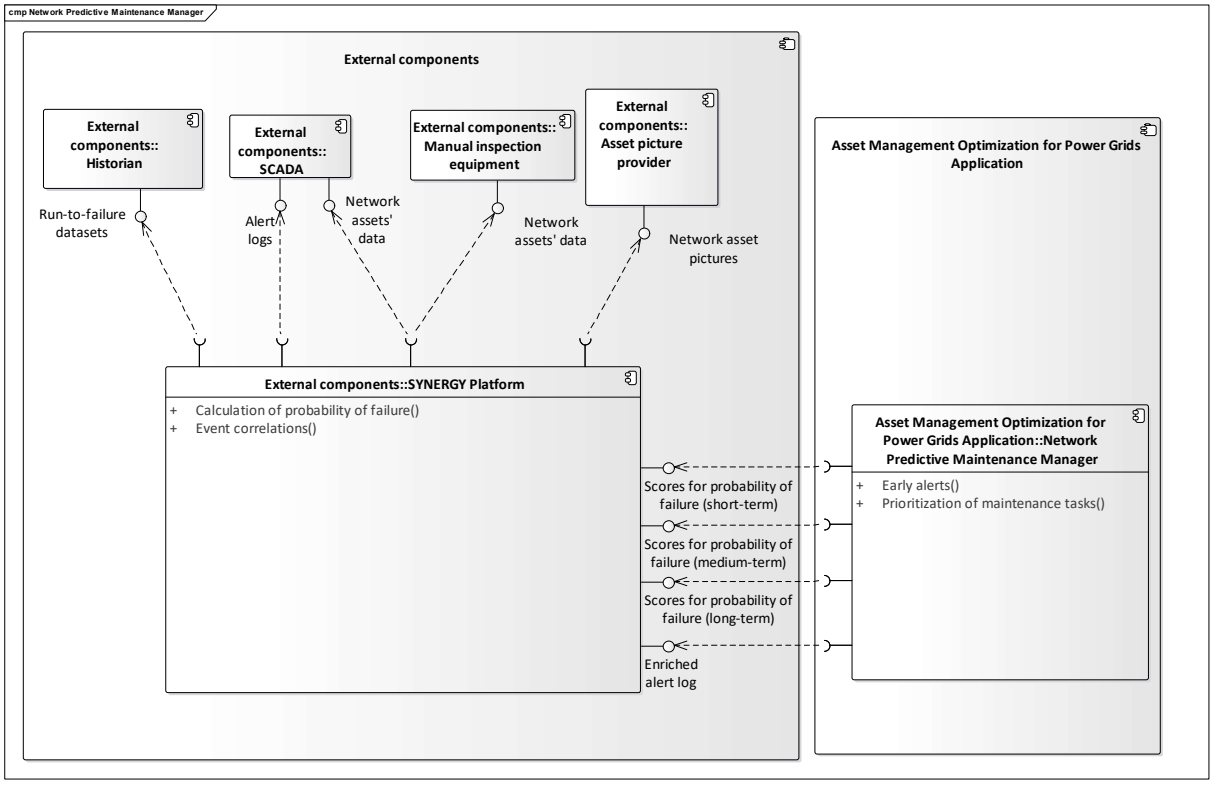

Figure 38: Network Predictive Maintenance Manager component diagram

As depicted in the component diagram, this component will make use of different models for failure prediction at different time ranges, which will be specialized for relevant combinations of asset and failure type. Additionally, the component will analyse historical alert logs from the DSO and TSO systems to find out correlations among those alerts, which can be used to trigger early alerts signaling potential cascade effects in the network under analysis.

The list of features offered by the Network Predictive Maintenance Manager includes:

Table 46: Network Predictive Maintenance Manager features

Feature	Description
NPM_1	Probability scores of occurrence of failures: bringing together all data linked to a particular network asset, the component will estimate the probability of failure within different time ranges

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NPM_2	Prioritization of maintenance tasks: the different metrics available for each network asset will be brought together with the technical maintenance specifications to assign relative maintenance priorities to each of the network assets under maintenance
NPM_3	Early alerts based on event correlation: due to the interconnected nature of the assets deployed in the power grid, cascading effects are usual, where the occurrence of certain events at certain locations have an impact on different assets and locations. By analysing historical alert logs, correlation among different alerts will be extracted in order to provide early alerts to the grid operator whenever a relevant situation is detected

The following tables provide a detailed view of the required data inputs, analytics that will be used on the available data and expected outcomes to cover the required functionalities.

Table 47: Network Predictive Maintenance Manager data inputs

SCADA data	**Data relevant to assets under maintenance that is automatically retrieved from SCADA.** **The specific properties to be collected depend on the type of asset under maintenance. This component is data agnostic, since it will be used for classification/profiling purposes. All available data will be considered for this purpose**
Expected update rate	Near real-time
Coverage	Assets under maintenance
Resolution	Seconds-Minutes range
Infrared pictures	**Infrared pictures provide valuable information for maintenance about the temperature of certain assets**
Expected update rate	Upon scheduled inspection

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 872734.

Coverage	Assets under maintenance
Resolution	-
Drone pictures	**Drone pictures provide valuable information for maintenance for visual inspection, about visible damage or operation conditions of certain assets**
Expected update rate	Upon scheduled inspection
Coverage	Assets under maintenance
Resolution	-
Measurements taken by maintenance personnel	**For some assets lacking availability of remote monitoring, maintenance personnel is in charge of manually collecting the relevant measurements.** **This component is data agnostic since it will be used for classification/profiling purposes. All available data will be considered for this purpose**
Expected update rate	Upon scheduled inspection
Coverage	Assets under maintenance
Resolution	-
Power grid event/alert log	**Log with the occurrence of different kind of events/alerts, bound to their location and time of occurrence**
Expected update rate	Near real-time
Coverage	Assets under maintenance
Resolution	-
Run-to-failure datasets	**Examples of temporal series for each type of asset and addressed issue, containing periods of normal operation and its evolution towards failure**

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Expected update rate	Once (for failure model training purposes)
Coverage	Different datasets covering all asset types and addressed issues
Resolution	-

Along with the definition of input data, the list of analytics processes required by the component is defined in the following table:

Table 48: Network Predictive Maintenance Manager analytics

Failure probability per asset (short-term)	**Determine the probability of failure (per asset and addressed issue) in the next 30 days**
Required inputs	Run-to-failure datasets covering addressed asset type, issue type and time range
Expected outputs	Failure prediction model (short-term)
Failure probability per asset (medium-term)	**Determine the probability of failure (per asset and addressed issue) in the next 6 months**
Required inputs	Run-to-failure datasets covering addressed asset type, issue type and time range
Expected outputs	Failure prediction model (medium-term)
Failure probability per asset (long-term)	**Determine the probability of failure (per asset and addressed issue) in the next 5 years**
Required inputs	Run-to-failure datasets covering addressed asset type, issue type and time range
Expected outputs	Failure prediction model (long-term)
Event correlations	**Upon occurrence of a particular sequence of events/alerts, provide early alerts on probable occurrence of future events/alerts**

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	The analytic will be based on sequence prediction algorithms trained with the historical alerts recorded by the grid operator
Required inputs	Power grid event/alert log
Expected outputs	Event correlation model

Details about the datasets offered by the SYNERGY Platform to be consumed and presented to end users in the UI of the Network Predictive Maintenance Manager are presented in the following table:

Table 49: Network Predictive Maintenance Manager outcomes

Failure probability per asset (short-term)	**For each asset and issue type, probability of failure in the next 30 days**
Expected update rate	Daily
Coverage	Asset type Issue type
Resolution	-
Failure probability per asset (medium-term)	**For each asset and issue type, probability of failure in the next 6 months**
Expected update rate	Daily
Coverage	Asset type Issue type
Resolution	-
Failure probability per asset (long-term)	**For each asset and issue type, probability of failure in the next 5 years**
Expected update rate	Daily

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Coverage	Asset type Issue type
Resolution	-
Early alerts	**Prediction of alerts that will take place in near future (next hours)**
Expected update rate	Near real-time
Coverage	Power grid under maintenance
Resolution	Affected asset Type of issue/alert

3.4.2 User stories

The user interface will be provided in the form of a web application. The maintenance operators of DSOs and TSOs will have access to a number of visualizations over the data processed and results offered by the components of the application. Access to the application will be provided by using the same credentials as the maintenance operators use in the SYNERGY Platform.

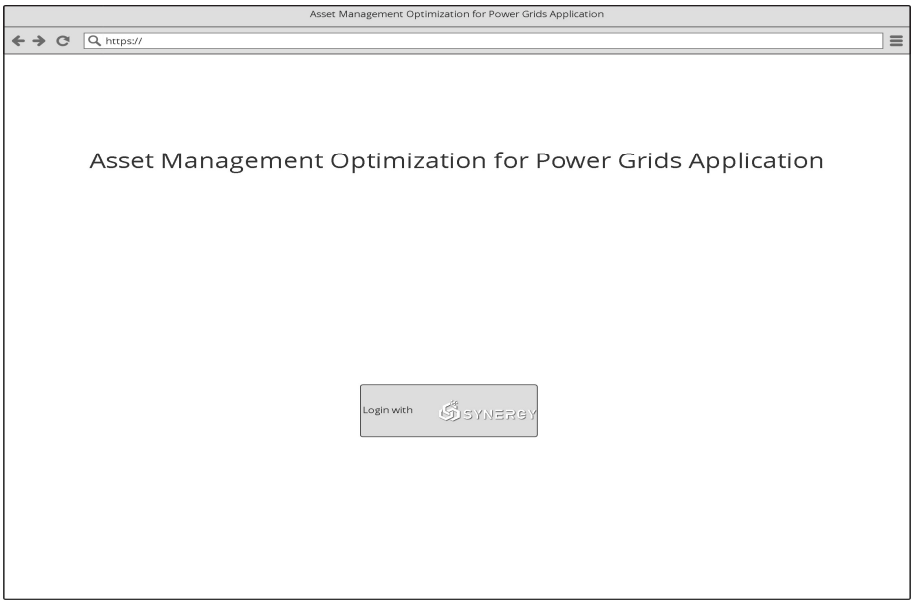

Figure 39: Asset Management Optimization log in

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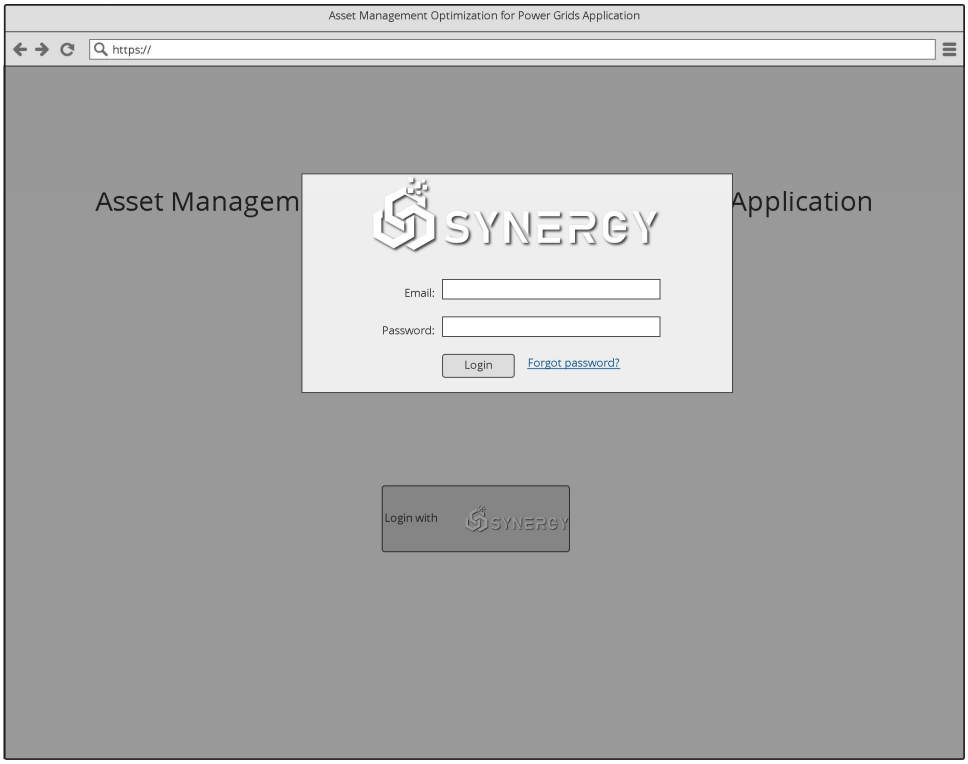

Figure 40: Asset Management Optimization log in

3.4.2.1 Health Status

The Health status menu will provide the visualization of all assets under maintenance details. The first site will display a summary table with the assets, their health status and the timestamp this status refers to. In order to simplify navigation, a form is included to allow filtering per asset type or health score. On the right hand side a map displays the geolocation of the elements shown in the table. By clicking on those elements (both in the table and in the map), the user gets redirected to the *Asset Details* site.

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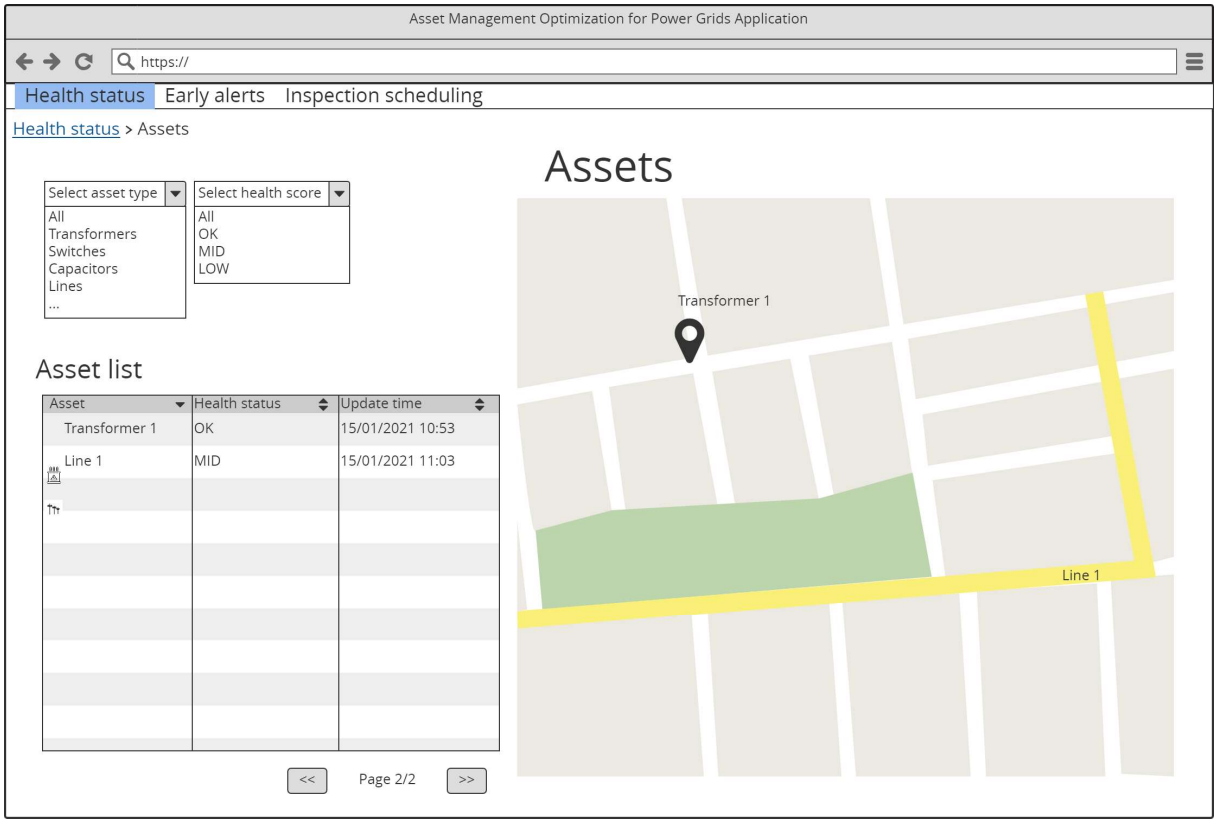

Figure 41: Asset Management Optimization- Assets details

The *Asset Details* site gives access to all the details considered by the application for each one of the assets.

The left-hand side presents the list of elements under maintenance in a tree view, to facilitate the navigation and search of the assets.

Upon selection of one of the elements, the following information is displayed:

- Static information about the asset
- Current health status (OK, MID, LOW), accompanied by the timestamp it was calculated
- Probability of failure. In the case that the application has applicable probability of failure models for this particular type of assets, a combo box will be shown, giving access to the probability of failure scores for this particular asset and issue type
- Chart displaying the selected metric(s) for the selected time range. A combo box will be available to select one or two of the available metrics for the selected asset.

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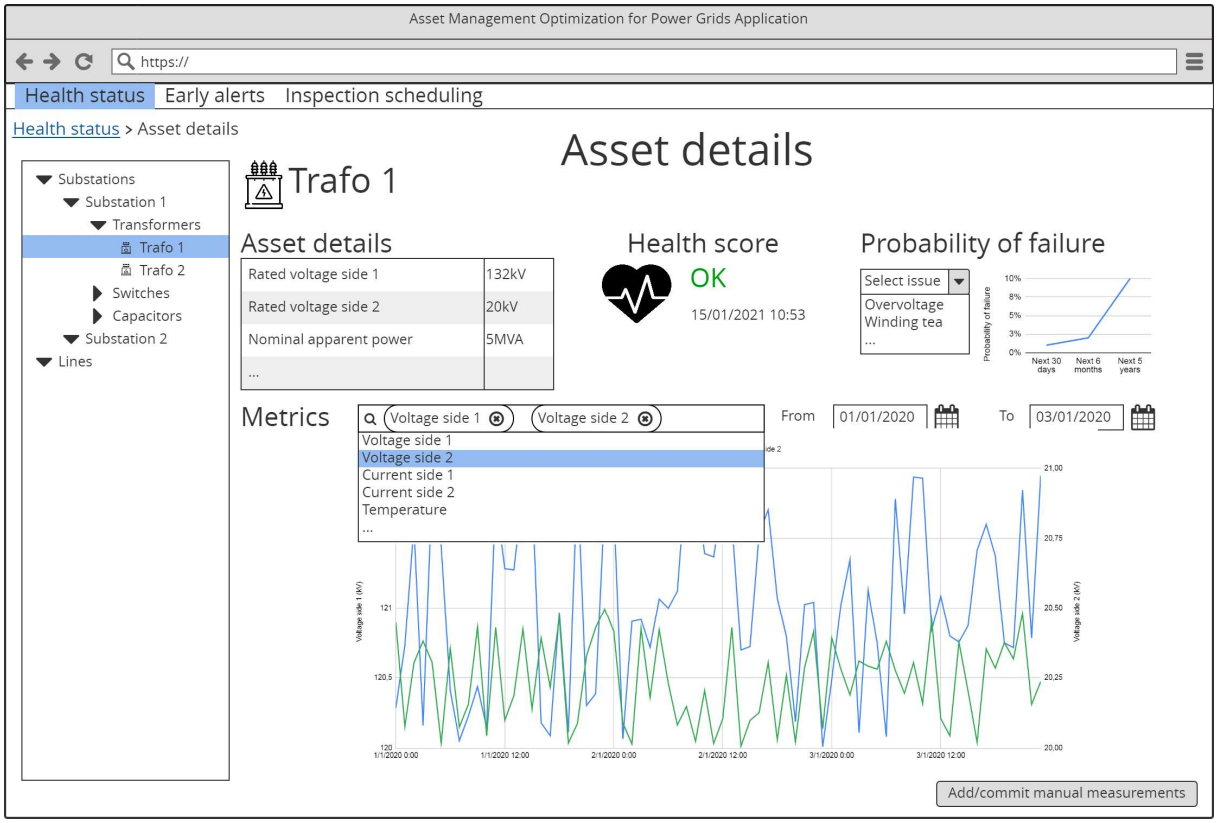

Figure 42: Asset Management Optimization- Assets details

The *Asset details* site will also offer the possibility to manually upload related measurements to the platform, which may be obtained during physical inspections of assets that may not be telemetered. Additionally, in the cases in which measurements have been provided directly by the field personnel with the mobile user interface described in section **¡Error! No se encuentra el origen de la referencia.**, fields will be prefilled with the provided data, allowing the maintenance operator to check, assess its validity and commit the measurements to the system. Upon upload of the new measurements, all relevant health and probability of failure indicators will get updated.

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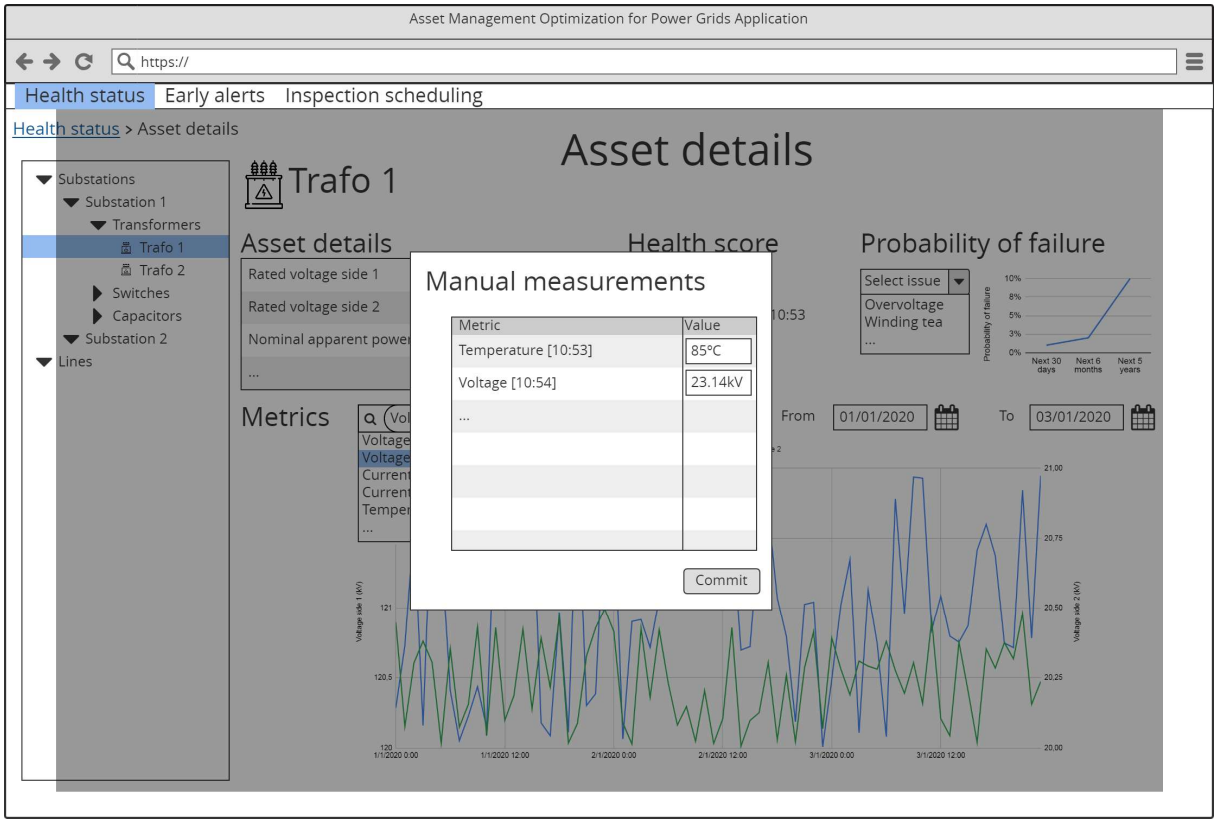

Figure 43: Asset Management Optimization- Assets details

3.4.2.2 Early Alerts

The *Early alerts* site displays an alert log of the monitored systems, which is enriched with the outputs of the *Network Predictive Maintenance Management* component.

The main part of the site will display a table with the relevant details of the alerts that are read from the SCADA and other systems of the DSO/TSO that are integrated in the SYNERGY Platform. This table will additionally incorporate *pre-emptive alerts*, which correspond to events the *Network Predictive Maintenance Manager* estimates are going to happen in the near future, based on the evolution of recent alerts and correlations that are detected and modelled using historical data.

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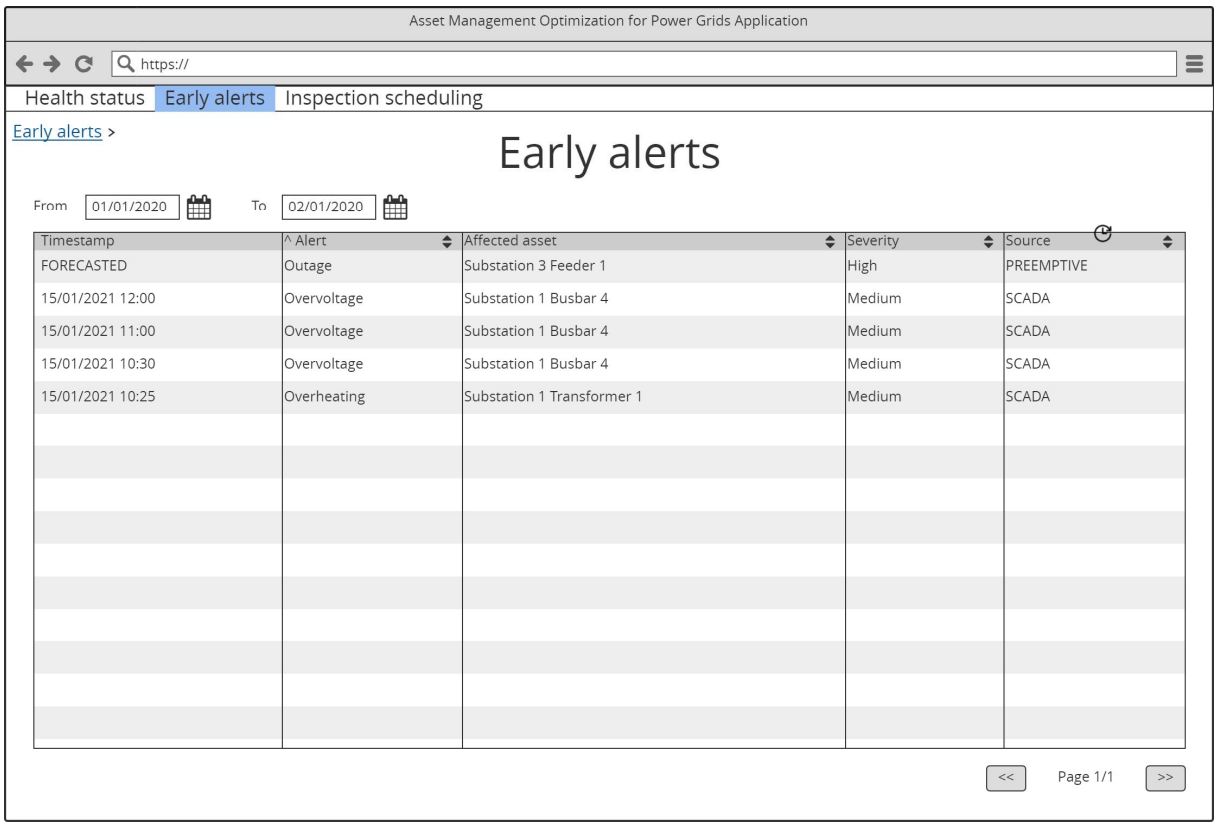

Figure 44: Asset Management Optimization- Early Alerts

3.4.2.3 Inspection Scheduling

The *Inspection scheduling* site displays a proposal for asset inspection. Based on the health score, short-term probability of failure (for the different considered issues) and impact level, the application will compose a ranked list of the assets that can be used to schedule the inspection visits by the maintenance staff, prioritizing those assets that accordingly to the data available and the results of the different analytics need more attention. By selecting an element of the table, relevant information about the asset, including static information and its geolocation, will be presented. A button will be presented, allowing the user to navigate to the corresponding asset details as described at section **¡Error! No se encuentra el origen de la referencia.**.

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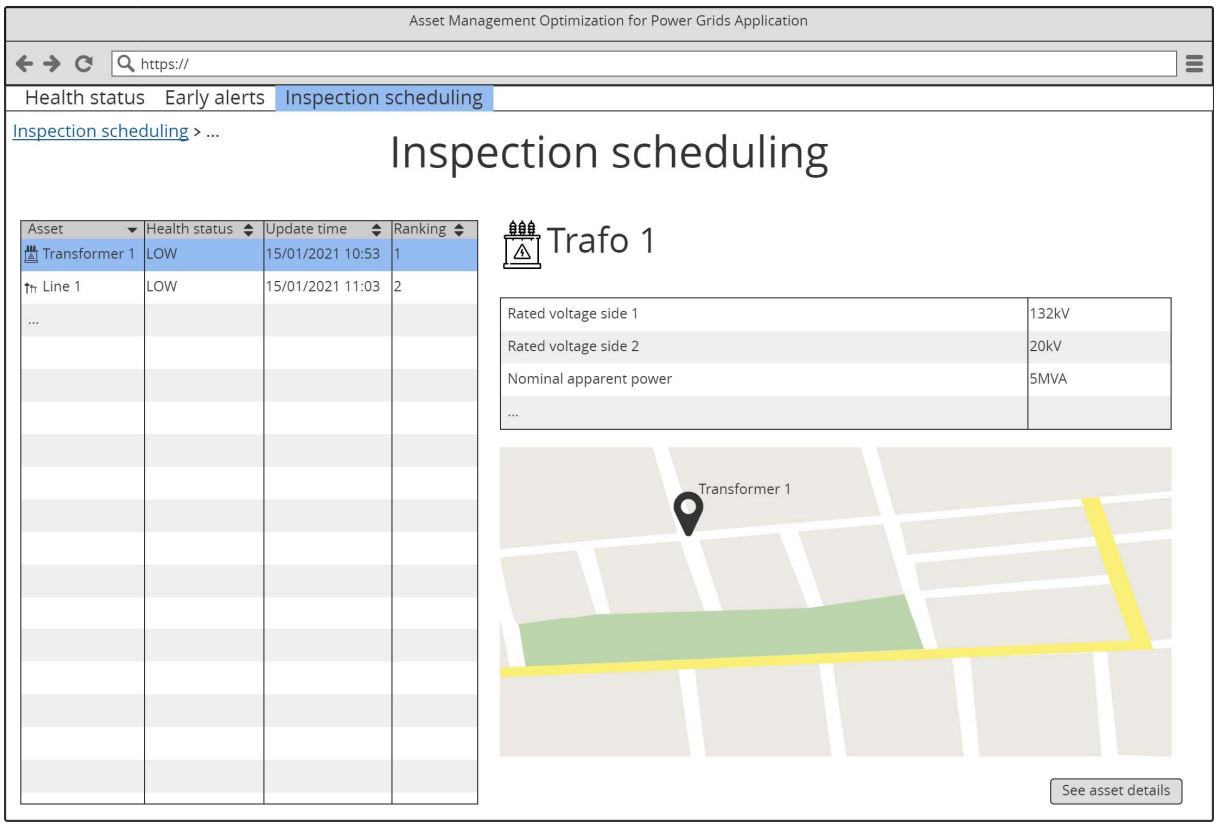

Figure 45: Asset Management Optimization- Inspection Scheduling

3.4.2.4 AR/VR visualization

The augmented reality / virtual reality visualization is designed as an additional visualization interface for the *Asset Management Optimization for Power Grids Application*. Both AR and VR can be multisensory: visual, auditory, haptic, somatosensory and olfactory, however there is a fundamental difference between VR and AR that is reflected into the usability of the technologies for the best user experience.

Virtual reality (VR) normally requires a virtual model of the world, either real one or a fully simulated one. The VR is a wholly simulated difference - the term VR has in practice became synonymous with the so-called *immersive* virtual reality, based on specialized devices that project the images and sounds to the user and immerse the user into a virtual world. The VR can be deployed on classic computer screens but can also utilize dedicated headset devices that follow the movement of user's head and adjust the presented image accordingly. VR headsets can be based on dedicated hardware headsets

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such as Oculus[3] or Vive[4], either tethered to a computer or with standalone computers. Mobile device mounts, such as very popular Google Cardboard[5], convert the mobile phone into a VR headset screen and have also become popular, given that mobile phones already include screens of very high quality, accelerometers, and cameras.

Augmented reality (AR), on the other hand, is an interactive experience of a *real-world* environment, where the objects residing real world are enhanced by computer-generated perceptual information. The computer-generated objects augment the real-world experience, thus the name augmented reality. An AR system that fulfils three basic features: a combination of real and virtual worlds, real-time interaction, and accurate 3D registration of virtual and real objects. The overlaid sensory information can either be constructive (i.e. additive to the natural environment), or destructive (i.e. masking of the natural environment). There are numerous examples of mobile-device based AR solutions, but there are also hardware devices dedicated to augmented reality such as Microsoft Hololens[6].

In virtual reality the users' perception is fully based on virtual information, while in the AR the user enhances the real world with the virtually added information. In the context of this application suite, a VR visualization is more suitable for office workers, while on the other hand AR is a better solution for field workers and there are numerous successful applications of AR in field work.

Considering the software technologies used for AR/VR visualization, there are two competing technologies in the AR/VR space: Unity[7] and Unreal Engine[8]. Both platforms have their origins in game development, and both platforms provide cross-platform deployment functionality.

The principal AR advantages for the field work are related to the field workers assistance in providing on-the-go real time information from the asset management app. In practice, this means visually

[3] Oculus (owned by Facebook), https://www.oculus.com/

[4] VIVE (owned by HTC), https://www.vive.com/us/

[5] Google Cardboard: https://arvr.google.com/cardboard/

[6] Microsoft Hololens: https://www.microsoft.com/en-us/hololens

[7] Unity Real Time Development Platform, https://unity.com/

[8] Epic Games Unreal Engine, https://www.unrealengine.com/en-US/

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presenting the asset data next to the actual asset. In order to do so, physical printed or etched visual markers placed on the assets have been proven to be a very reliable choice. This approach is reliable and cost-effective in an industrial environment as the printed markers do not require power. Most popular marker technologies have a comparatively high degree of redundancy, so damaged or dirty markers also work. There is virtually no issue in security too: the markers, even if decoded by an adversary party, do not hold any sensitive information nor do they require updates. The marker only stores an internal identifier of the asset.

The two distinct ways of making the asset management application VR-enabled, as described above, have been presented to the DSO end users. Considering the existing established asset management procedures in place at the end users, there has been a clear preference for the AR technology as it seemed to provide more added value to the existing procedures of asset management, especially when focused on field workers.

A combination of in-the-field AR-enabled mobile application front end and an additional review step in the office via web application has been selected. The mobile application will use identifiers (visual tags) to identify the assets and then get the data from the asset management optimization application, which will enhance the field workers' user experience of the field workers. This has a potential to streamline the maintenance process and increase the overall maintenance data quality.

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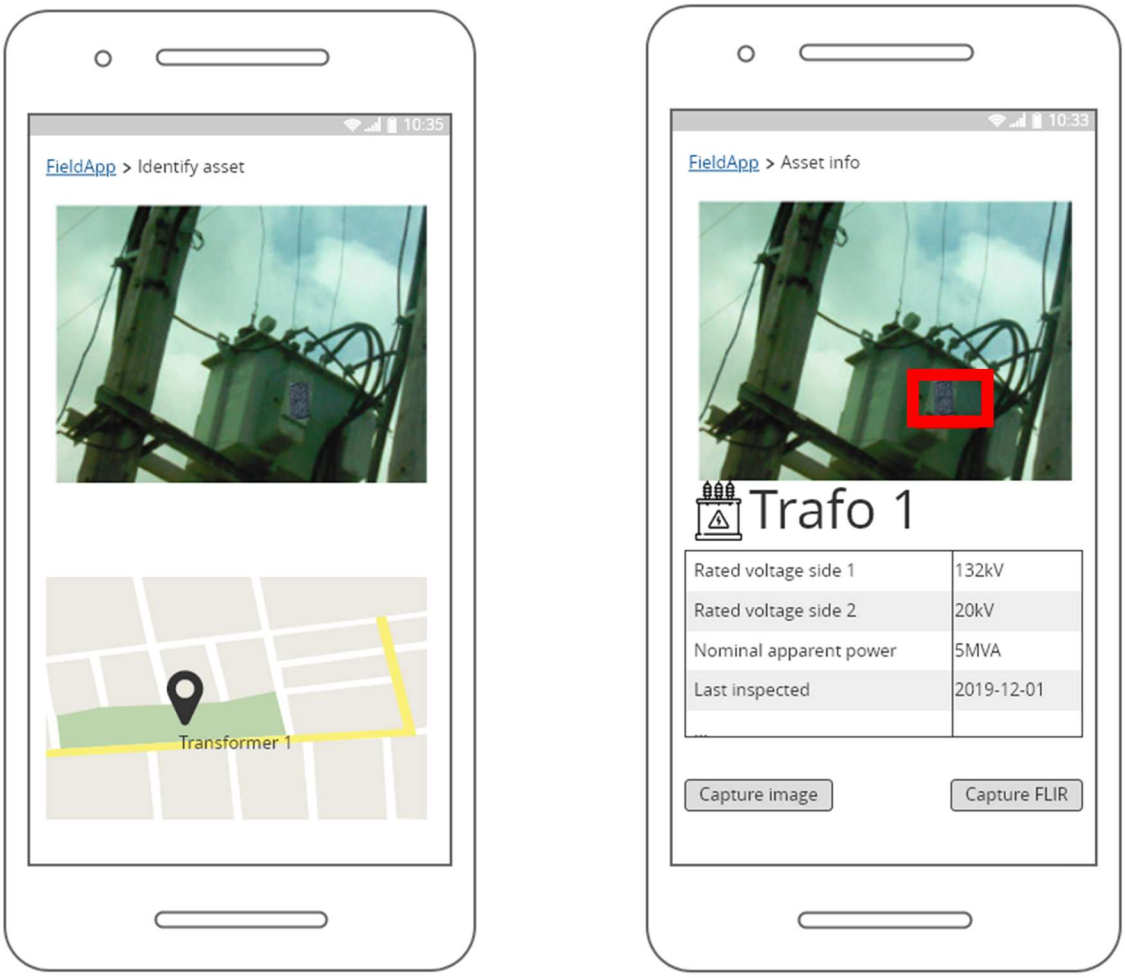

Figure 46: in-the-field AR-enabled mobile application front end and asset info

The main screen of the mobile application allows the users to identify the asset and after decoding the visual identifier to get the asset information stored in the asset management application – this screen of the mobile application has its equivalent in the web application, and allows the field worker to visualize the same data that is visible in the web application. Manual selection of the asset will also be permitted for the cases where the marker does not function or is obscured completely. This way the field workers are able to easily identify the asset they are considering, and can proceed with capturing the visual image of the asset, or, if the equipment permits, capture the FLIR thermal image of the asset. In both cases, the image captured is tied to the asset being identified.

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Figure 47: in-the-field AR-enabled mobile application Capture image and FLIR

The mobile application represents an equivalent to manual entry of the data in the web front end, and the AR functionality added value is easier identification and visualization of the asset, as well as tying the collected media to this particular asset in a more reliable fashion. Overall, this way the AR front end to the asset management application would make the field worker workflow easier and less error-prone. However, this does not eliminate errors completely, and given the restrictions of the mobile device it is reasonable to expect errors in data entry from the field. For this reason all the data collected in the field is considered pending and would be committed after the field worker returns to the office and revisits the collected data, as described on section **¡Error! No se encuentra el origen de la referencia.**.

3.4.3 Exploited technology stack

The design of this component will follow a micro-services approach, where different atomic features will be developed in will defined software modules offering an API for enabling interactions with

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external components or submodules. The proposed technology to facilitate the micro-services-based deployment is Docker[9], packaging each of the components as an independent docker image.

With regards to the software libraries and platforms foreseen for the development of the user interface, those include NodeJS[10] for backend services, Meteor[11] for front-end/back-end communication and reactive data delivery to clients, and React[12] for reusable and highly modular front-end development. In order to host component-specific data, MongoDB[13] database is proposed.

Regarding the technology stack of the AR visualization module, it will be composed of two parts: an "in the field" mobile app for Android and iOS devices, and some of accompanying functionalities will be implemented in the asset management web application. The mobile application will be developed in Unity or Unreal Engine and deployed as a native application for iOS and Android to respective stores. The mobile application is designed to be an additional avenue of visualization to the *Asset Management Optimization for Power Grids Application*. The AR-based mobile application should be considered a part of the Asset Management application, with which it will exchange data.

The AR interface builds upon the experiences of KONČAR in the development of KONČAR RTGo system. This is an AR-based system that assists the field workers by providing on-the-go interface to SCADA data in a secure visual manner suitable for field workers.

[9] https://www.docker.com/

[10] https://nodejs.org/en/

[11] https://www.meteor.com/

[12] https://reactjs.org/

[13] https://www.mongodb.com/

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Figure 48: marker installation inside a wind power plant

To illustrate the AR technology and marker-based AR functionality, the figure above depicts the marker installation inside of a wind power plant nacelle and the RTGo AR system operation. On the left is a marker. On the right, the screenshot from the mobile device pointed towards the marker is shown where the marker image is replaced with the live data gathered directly from the SCADA system.

An analogous approach will be taken in the development of the AR application. More precisely, the visual markers have been selected due to their good performance within the RTGo context, and the AR module will communicate with the main asset management for power grids application, as presented in the interface mock ups above. In other words while the AR-based module for SYNERGY will build on the RTGo experience, it will be a new development tailored to integrate well into the asset management for power grids application.

Finally, the data analytics and optimizations libraries to be used in the application will be aligned with the frameworks and libraries that will be supported in the Data Analytics Services Bundle in the SYNERGY Cloud Platform.

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4 Conclusions

Deliverable D5.1, entitled “Detailed functionality specification and design of the Asset Management Tool Suite for TSOs, DSOs and RES Operators” aims to describe and present the design and the functionalities specifications of the applications composing the Asset Management Tool Suite.

At first, the context of WP5 energy applications is given with regards to the SYNERGY use cases and the overall architecture of the SYNERGY platform. Also, an overview of existing solutions from the relevant stakeholders, also in relation to D10.5 Market Radar v1, is presented, which contains BaU, state of the art tools, platforms and other EU funded projects.

Next, the technical specifications of the four applications are introduced, including the components of each of the applications, the features proposed for each component, the internal architecture of the applications, data inputs and expected outcomes. Also, the expected user interface of the proposed applications is presented in the form of mock ups and the description of user stories.

D5.1 is the first deliverable out of the three total deliverables of WP5. The next step for all the four active tasks of WP5, is the initiation of the development activities for the tool suite, with the 1st release of the tool suite to be planned for M22 and finally in M42, the final version of these applications.

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